EXPERT SYSTEM FOR THE DESIGN OF SHELL AND TUBE HEAT EXCHANGER WITHOUT PHASE CHANGE

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CERTIFICATE

This is to certify that the work entitled 'Expert System for the Design of Shell and Tube Heat Exchanger Without Phase Change' by Avinash C. Bhaskare' has been carried out under our supervision and has not been submitted elsewhere for the award of a degree.

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TO MY

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ABSTRACT

An expert system for the thermal design of single phase flow shell and tube heat exchangers (STHE) has been developed. The system is highly interactive which gathers information about the problem by asking the user necessary questions, and giving him help and explanation if required.

This expert system is based on logic programming where knowledge is seperate from control. The inference algorithm used in the expert system shell is SLD-resolution. The query tree is developed by this resolution and depends upon user response.

The design process of STHE has been studied and has been transformed into a knowledge base comprising of rules, facts, questions and explanations. The process of encoding knowledge into rules is also discussed. The modified Bell-Delaware method is used for the shell side analysis and Kern's method for the tube side analysis. The shell side analysis considers the non-ideal cross flow as it occurs in an actual STHE and suitable correction factors are calculated to take into account the deviation from the ideal cross flow.

NOMENCLATURE

a	Constant
A_o	Total heat transfer area, equation (3.1b), m^2
A^*	Constant, equation (3.12), mm^{-1}
$(A_o)_{req}$	Actual area required for heat transfer, equation (3.90), m^2
A_{tot}	Total flow area available on the tube side, equation (3.76), mm^2
A_{tp}	Flow area per pass required to maintain a velocity v_t, ms^{-1} on the tube side , equation (3.77), mm^{-1}
b	Constant
B_c	Segmental baffle cut as a percent of D_s, equation (3.22)
C_1	Tube field layout constant, equation (3.12)
C_{br}, C_{bp}	Constants
C_{p_s}, C_{p_t}	Specific heat of shell and tube side fluids, equation (3.1a) J $kg^{-1}K^{-1}$
D_{ctl}	Tube bundle pitch circle diameter, equation (3.17) mm
D_{otl}	Outside diameter of the tube bundle, equation (3.37), mm
D_s	Shell diameter, equation (3.11), mm
D_t	Tube diameter, mm
D_w	Equivalent hydraulic diameter, equation (3.32)mm

e	Constant
F	Log mean temperature difference correction factor, equation (3.5)
F_c	Fraction number of tubes in pure cross flow between baffle tips, equation (3.28)
f_i	Ideal tube bank friction factor, equation (3.67)
F_{sbp}	Ratio of bundle bypass area S_b to overall cross flow area S_m, equation (3.39)
F_w	Fraction number of tubes in the baffle window, equation (3.27)
$h_{s_{ideal}}$	Ideal tube bank heat transfer coefficient, equation (3.60), $Wm^{-2}K^{-1}$
h_s, h_t	Heat transfer coefficients for shell side and tube side fluids, equations (3.66) and (3.87), $Wm^{-2}K^{-1}$
J_b	Bundle bypass correction factor for heat transfer, (3.52)
J_c	Segmental baffle window correction factor for heat transfer, equation (3.47)
j_i	Ideal tube bank heat transfer factor, equations (3.57), (3.58), (3.59)
J_l	Baffle leakage correction factor for heat transfer, equation (3.50)
J_r	Heat transfer correction factor for adverse temperature gradient in laminar flow, equations, (3.54) and (3.56)
k_s, k_t	Thermal conductivity of the shell and tube side fluid, $Wm^{-1}K^{-1}$

k_w Tube wall thermal conductivity, $Wm^{-1}K^{-1}$

L_{bb} Tube bundle to shell diametral clearance, equations (3.13) through (3.16), mm

L_{bc} Central baffle spacing, equation (3.21), mm

L_{pp} Flow direction distance between two tubes, equation (3.33), mm

L_{pl} Half of tube lane partition, equation (3.32), mm

L_s Length of the shell, equation (3.11), mm

L_{sb} Diametral shell to baffle clearance, equation (3.40) mm

L_{ta} Effective tube length for heat transfer, equation (3.11), mm

L_{tb} Diametral tube to baffle hole clearance, equation (3.43), mm

L_{to} Nominal tube length, equation (3.18), mm

L_{tp} Tube pitch, equation (3.12a), mm

$L_{tp_{eff}}$ Effective tube pitch, equation (3.25), mm

L_{ts} Tube sheet thickness, equation (3.19), mm

L_{wp} Effective distance of cross flow penetration, (3.34), mm

$\dot{m}_s, \dot{m}_t$ Mass velocity of the shell side and tube side fluids, equations (3.44) and (3.81), $Kgm^{-2}s^{-1}$

$\dot{M}_s, \dot{M}_t$ Mass flow rates of shell side and tube side fluid, $kg\ s^{-1}$

N_b Total number of baffles, equation (3.20)

N_c	Number of tube rows crossed in the heat exchanger, equation (3.55)
N_{ss}	Number of sealing strip pairs, equation (3.52)
N_t	Total number of tubes, equation (3.79)
N_{tcc}	Number of effective tube rows crossed between baffle tips, equation (3.33)
N_{tcw}	Effective tube rows crossed in one baffle spacing, equation (3.35)
N_{tp}	Number of tube side passes, equation (3.78)
N_{tw}	Number of tubes in the segmental baffle window, equation (3.30)
p	Constant, equation (3.51)
P	Thermal effectivess, equation (3.7)
Pr_s, Pr_t	Prandtl number of shell side and tube side fluids, equations (3.46) and (3.83)
Q_o	Heat duty of the heat exchanger, equation (3.1a), W
R	Heat capacity ratio, equation (3.6)
R_b	Bundle bypass correction factor for pressure drop, equation (3.53)
Re_s, Re_t	Reynolds number of shell side and tube side fluids, equation (3.45)
R_{f_s}, R_{f_t}	Fouling factors for heat transfer, equation (3.2), m^2KW^{-1}
r_i, r_o	Inside and outside radius of the tubes, equation (3.2), mm

R_1	Baffle leakage correction factor for pressure drop, equation (3.51)
r_{lm}	Constant, equation (3.48)
r_s, r_{ss}	Constants, equation(3.49) and (3.52)
R_s	End zone correction factor for pressure drop, equation (3.56a)
S_b	Bundle to shell bypass area within one baffle spacing, equation (3.36), mm^2
S_m	Cross flow area at shell centreline within one baffle spacing, equation (3.25),mm^2
S_{sb}	Shell to baffle leakage area, equation (3.41),mm^2
S_{tb}	Tube to baffle hole leakage area per baffle, equation (3.42), mm^2
S_w	Net cross flow area through one baffle window, equation (3.31), mm^2
S_{wg}	Gross window flow area without tubes in one window, equation (3.26), mm^2
S_{wt}	Segmental baffle window flow area occupied by N_t tubes, equation(3.29), mm^2
T	Temperature, equation (3.63),K
$T_{c_{in}}, T_{c_{out}}$	Inlet and outlet temperatures of the fluid, equation (3.4),^oC
$T_{h_{in}}, T_{h_{out}}$	Inlet and outlet temperatures of the hot fluid, equation (3.4),^oC
T_{si}, T_{so}	Inlet and outlet temperatures of the shell side fluid, equation (3.5),^oC

$T_{s_{av}}, T_{t_{av}}$	Average shell side and tube side temperatures, equation (3.62), ^{o}C
T_{ti}, T_{to}	Inlet and outlet temperature of the tube side fluid, equation (3.5), ^{o}C
t_t	Tube wall thickness, mm
T_w	Tube wall temperature, equation (3.62), ^{o}C
U_o	Overall heat transfer coefficient, equation (3.2), $Wm^{-2}K^{-1}$
v_t	Velocity of the tube side fluid inside the tubes, equation (3.77) ms^{-1}

GREEK LETTERS

∂	Constant
Δp_{bi}	Ideal tube bank pressure drop, equation (371) kPa
Δp_c	Pressure drop in pure cross flow, equation (3.72), kPa
Δp_e	Pressure drop in end zones, equation (3.51a)kPa
Δp_r	Pressure drop associated with change of direction in the tube side passes, equation (3.89), kPa
Δp_s	Total shell side pressure drop, equation (3.66a)kPa
Δp_t	Pressure drop inside tubes, equation (3.89), kPa
Δp_{total}	Total tube side pressure drop, equation (3.89b), kPa
$\Delta T_s, \Delta T_t$	Absolute temperature difference between inlet and outlet temperatures for the shell and tube side fluids, equation (3.1b), ^{o}C

ΔT_{LM}	Log mean temperature difference, equation (3.4), ^{o}C
η_s, η_t	Absolute viscosity of the shell side and tube side fluid at their respective average temperature, Cp
η_{sw}	Absolute viscosity of the shell side fluid at the tube wall temperature, equation (3.61)
θ_{ds}	Centriangle of baffle cut, equation (3.23), rad
θ_{ctl}	Upper centriangle of baffle cut, equation (3.24), rad
θ_{tp}	Tube layout angle, deg
ρ_s, ρ_t	Density of the shell side and tube side fluids, kg m^{-3}

ABBREVIATIONS

AI	Artificial Intelligence
HE	Heat Exchanger
LMTD	Log Mean temperature difference
MTD	Mean temperature difference
STHE	Shell and tube heat exchanger

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CHAPTER 1

INTRODUCTION

1.1 EXPERT SYSTEMS AND AI (Sangal, '85):

It has been the aim of Artificial Intelligence (AI) to develop systems which behave like human beings. This means inventing machines which can interact like the human being, i.e. ask questions, gain knowledge and tell what they are doing.

Expert systems are problem-solving programs that solve important problems which are generally solved by human experts. In this thesis, we will be dealing with an expert system for the design of Heat Exchangers.

By looking at the scenario in which the human expert performs, one can say the following about an expert system. An expert system, besides having the ability to solve problems must engage in a dialogue with the user to acquire the relevant details of the problems, be able to explain its problem solving process, be easily modifiable to take care of new discoveries, and be able to deal with partial information.

Recently, several factors have motivated research on expert systems. These systems are designed to manipulate and explore symbolically expressed problems that are

difficult for human researchers to solve. A problem, suitable for building an expert system is one which has a number of possible solutions. As the number of solutions increase , it becomes difficult for a human being to discover the correct solutions. The ability of AI systems to deal with larger solution spaces is important in that it extends the type of problem that can be solved with the same conceptual tools.

Most notably, expert systems promise to solve hard problems that require the best (most expensive) human expertise. The very codification of expertise insuitable form for an expert system can lead to new insights into the structure of the domain, or new ideas about how to teach it.

A system is considered an expert system if it meets the following criteria:

1. The system gives correct answers or gives useful advice.
2. Interact with the user to acquire relevant data.
3. Justify its solutions.
4. Explain why it has asked a question, i.e., the line of reasoning being followed.

1.2 STRUCTURE OF THE EXPERT SYSTEM:

Building an expert system by writing a large program that incorporates all the domain knowledge prescriptively (as procedure , program steps, etc) does not work. Such a system lacks flexibility,can not deal with partial

information easily and, is not easy to change.

In the present expert system, the knowledge about the domain of the problem (design of STHE) is different from the procedure of how to apply the knowledge. The knowledge is represented as rules and facts, and the ' expert system shell' is an intricate meachanism which decides how to select and apply the rules. This is essentially the'rule based expert system'.

While developing an expert system, as mentioned earlier, enormous amount of knowledge in terms of facts and rules is required. The present work is an attempt to develop an expert system for the design of Heat Exchange Equipment. Srinivas (1985) initiated the work in this area, and formulated rules for the selection of Heat Exchange Equipment.

It can be seen from the literature available on the design of HE that a very large number of decisions involving logic have to be made in the actual design, e.g. deciding the type of the bundle, the type of pitch layout etc. Many times, some parameters may already be known to the designer and therefore, need not be computed. The final design is obtained, basically by trial and error until certain criteria are satisfied. There is no unique solution to the design problem. Whichever (solution) suits the needs of the user is ultimately the chosen solution. All the necessary design information needs to be structured

properly to develop an expert system.

1.3 PRESENT WORK:

The objective of the present work is to develop an expert system for the thermal design of shell and tube heat exchangers, without phase change.

1.4 ORGANISATION OF THE THESIS:

Chapter 2 discusses the Expert System Shell which is the basis for the Expert System developed during the course of present work. Chapter 3 gives all the equations and the procedure for the design of shell and Tube Heat Exchangers. Chapter 4 discusses the structuring of the knowledge base used in the expert system developed. Chapter 5 discusses how to use the system and the results obtained for a given situation including the sample sessions. Limitations of the system and suggestions for future work are also recorded.

CHAPTER 2

AN EXPERT SYSTEM SHELL

2.1 REVIEW OF LOGIC PROGRAMING:

2.1.1 Programing Language:

The programing language used here is LISP. LISP has the following distinet advantages over other languages (Avron, 1982).

a. Applicative Style- The data structure is a list. Instead of being described as a sequence in which operations are performed, Even a LISP environment is a large LISP program. successively.

b. Programs as Data- The other unique characteristics of LISP is that the programs are represented the same as data. LISP program. Even a LISP environment is a large.

c. Association - LISP symbols namely atoms can have one or several properties associated with different property attributes.

2.1.2 Predicates, Formula, Rule, Pattern Matching:

I. Pattern Matching:

The database can be distinctly divided into 2 types:

a. Pattern which can have zero or more occureances of the wild card and

b. A data item or a fact which does not have a wile card

where a wild card is a variable which can take any value. Example of a Robot trying to dig a treasure (Nilsson, 1979) Goal seeking example of MARK.

MARK is a robot for finding out the buried treasure. We can define some patterns and facts for this example.

(1) (At < position>)

(Have shovel)

(Have map)

(Treasure-site < position>)

(Inview treasure)

are some examples of facts.

'At' is a predicate which has one argument i.e. position, 'Have' is a predicate which can have either'shovel' or 'map' or any other thing as its argument. We say a pattern matches a fact if we are able to find a value for the wild card, such that after substituting this value in the pattern, we are able to get the fact. e.g. if we have a fact as .

(2) (Have shovel)

and the pattern is

(3) (Have ?what)

Clearly, the variable ? what matches the fact, and the corresponding match is 'shovel' matching of a fact is always a corresponding fact; a pattern may match with a fact or another pattern also.

Pattern matching with more than or one variable can be illustrated by the following example:

(4) (Colour apple ?X)

(5) (Colour ?Y red)

The patterns (4) and (5) match the fact (3)

(6) (Colour apple red)

and the corresponding match of X and Y variables can be given as

(7) ((? X Red) (?Y apple)) :- ALIST

Alist is a list of lists containing a variable and its corresponding match from the fact.

It may be noted that a variable can match with another variable also.

e.g. the pattern (4) (Colour ?X ?Z)

can match with another pattern (5) (Colour ?Y red) giving an ALIST as-

(8) ((?X ?Y) (?Z red))

A variable is internally represented as a list ($ var X). This is done by the Read macro /? which automatically returns a list of $ VAR and the atom following '?'. We can also have patterns that can match with several facts.

e.g. a pattern (9) (Colour (fruit ?X) ?Y)

can match with

(10) (Colour (fruit apple) red)

(11) (Colour (fruit mango) yellow) etc.

II. Rule

Now going back to our example of MARK, a robot to dig treasure. We define a Rule as an assertion of the type

(12) B ⟵ A1, A2, A3, A4 ...... AN

Cond ....$N \geq 0$

where A1, A2, A3 ..... AN are called as atomic formulas Rule 12 states that if the atomic formulae A1 to AN are true then B is true.

III. Atomic Formula:

An atomic formula is a predicate, applied to their respective arguments, of which at least one is a variable; In our example, since MARK is a treasure seeking Robot, he is under the control of a top level action called as ' find treasure'.

We can have different rules as

(13) (have ?X) ⟵ (Inview ?X)

(14) (excavate ?X) ⟵ (Treasuresite ?X)

(15) (pick-up ?X) ⟵ (inview ?X)

(16) (read ?X) ⟵ (have ?map)

and fact like

(17) (have map)

Then the goal given as (read ?X) will infer that the Robot has to (read map) since ?X matches with map from the database (17)

After reading the map, he will come to know the treasure site ⟶ B.

Applying rule (14) gives him a command to excavate the treasure site B.

After exacavating treasuresite B, the ' treasure' will be inview. i.e. a new fact (inview treasure) will be generated and applying rule 13, one can infer that he has treasure i.e. (have treasure).

The above mentioned actions are done in the ' Expert system shell'.

IV. Types of Variables (Avron, 1982):

1. Open Variable- a variable which matches to any element of a list and binds itself to that matching value.

2. Closed Variable - A variable may already have a binding, as above, and will match henceforth only to that particular value.

3. Restricted Variable- A variable may have restrictions placed on it, These restrictions are procedurally attached to it, in some way, for e.g. a Boolean predicate must be TRUE for the variable to match.

4. Segment Variables - They match to a sublist of any length, rather than to an element.

2.2 PRESENT SYSTEM AT THE USER LEVEL:

2.2.1 Types of Data Structures.

The data structures in this expert system shell are of the following type (Sangal, Forthcoming)

a. Facts- A predicate can have one or more facts stored as property list. A fact is defined as an unconditionally true assertion hence it is a Rule with a nil antecedent.

The syntax for fact is;

(((< predicate arg_{11} ..... arg_{1n} >) NIL Identifier 1)

((< predicate arg_{21} ...arg_{2n} >) NIL Identifier 2)

⋮ ⋮

((predicate arg_{m1} .....arg_{mn} >) NIL Identifier m))

where The arguments are just atoms and not variables. When a goal is given to the system, a fact is generated if rules that are applied succeed, and when the same goal is given once again, the system gets the values directly from the facts, thus saving the task of applying rules every time a same goal is given. Any inference is stored as a fact only if the context for the predicate is declared as True, or the inference has been made by asking the question.

b. Rules:

As seen earlier, a rule is an assertion of the form

$B \longleftarrow A_1 \; A_2 \; \ldots\ldots \; A_n$

i.e. B can be inferred if the atomic formulas $A_1, A_2, \ldots A_n$ are true.

A rule for a predicate is stored as a property list under the following syntax:

$$(((\langle \text{predicate}\rangle\ \langle \text{arg}_{11}\rangle\ \langle \text{arg}_{12}\rangle \ldots\ldots \langle \text{arg}_{1n}\rangle)$$

$$((A_{11})\quad (A_{12})\ \ldots\ldots A_{1_{p_1}}))\quad \text{Identifier}_1)$$

$$((\langle \text{predicate}\rangle\ \langle \text{arg}_{21}\rangle\ \langle \text{arg}_{22}\rangle \ldots\ldots \langle \text{arg}_{2n}\rangle)$$

$$((A_{21})\ (A_{22})\ \ldots\ (A_2P_2))\quad \text{Identifier}_2)$$

$$\vdots \qquad \vdots$$

$$((\langle \text{predicate}\rangle\ \langle \text{arg}_{m1}\rangle \ldots\ldots\ldots \langle \text{arg}_{mn}\rangle)$$

$$((A_{m1})\ (A_{m2})\ \ldots\ldots\ (A_{m\,p_m}))\quad \text{Identifier } m\ ))$$

where at least one of the argnment should be a vaiiable.

$l \longrightarrow$ no of arguments

$I \longrightarrow$ no of rules.

P = no of atomic formulas that have to be satisfied in order that the consequent of of the rule can be inferred.

c. Context (Avron, 1982)

The huge data base of the system is divided into sets called contexts. The basic idea is to repace the global database with a tree of distinct data bases called contexts the contexts are arranged in a tree because each tree represent a differnt state of world. As this state of world changes, a

context naturally gives rise to 'descendent' contexts which differ slightly. Most of the information in a given context will be the same as in the parent context just above it, so to save space, only the differences are stored. A process at any given time uses one specific context as its database the current context.

When a context for a predicate is declared true, the inference is stored as a fact for that predicate.

d. Question:

A predicate may have a question stored under the property list. Question is stored as a list and when the question has to be asked, a function 'ASK-USER' gets the question and prints it, and further waits for the response from the user.

When the user types the response, depending upon the answer given,

(1) If the response is ' Dontknow ' a tag 'T' is set under the property DONTKNOW, and this question will not be asked next time.

(2) If the response is 'Help', it prints out the various commands that are available, like what,Dontknow etc.

(3) If the response is 'Why', it types out the rule that has issued the current question.

(4) If the response is 'What', it types out the exapanation

available for that predicate. Explanation is usually a form of standard value table, or guidelines on what answer should be given .

(5) If the response is none of the above, then it takes it as the answer to the question and then stores it under the property fact.

e. Question-Proc:

If the question cannot be asked in a simple sentence, and require some procedure to be called we can use a question procedure.

f. Action-Predicate:

An action predicate when applied changes the database.

2.3. DEFINING RULES AND FACTS:

2.3.1 Facts:

As stated earlier a fact is an assertion which is always true for e.g. we know that the approximate film coefficients and fouling resistances for different types of fluids are as follows:

Type	h, W/m^2K	$R_f, m^2K/W$
1. Light liquid	1750.0	0.15×10^{-3}
2. Medium Liquid	1000.0	0.20×10^{-3}
3. Heavy liquid being cooled	300.0	0.15×10^{-3}
4. Heavy liquid being heated	500.0	0.15×10^{-3}

We can have predicate named App-film-foul which has the following arguments-

(App-film- foul <type of the fluid> < value of film coefficient> <value of Fouling Resistance>)

Hence the above table can be stored as a fact using the syntax of facts as follows,

(Defprop App-film-foul

(((App-film-foul Light 1750.0 $0.15X10^{-3}$) nil 1)

((App-film-foul Medium 1000.0 $0.20X10^{-3}$) nil 2)

((App-film-foul Heavy-hot 300.0 $0.15X10^{-3}$) nil 3)

((App-film-foul Heavy-cold 500.0 $0.15X10^{-3}$) nil 4)

) Facts)

Liquid being heated is the cold-fluid, and liquid being cooled is the hot-fluid hence the type of fluid is abbreviated accordingly.

2.3.2 Rules:

We know that a rule is an assertion whose consequent is true only if the atomic formulas in the antecedent are true. One can now take the example deciding which fluid to place on the shell side and tube side. The following set of rules can be used to determine which fluid is to be placed on the tube side:

The tube side will have

1. The corrosive fluid

2. The severely fouling fluid

3. The fluid having high mass-flow rate.

These rules are in order of importance i.e. if none of the two fluids is severly corrosive, then test which one is severely fouling if both the rules fail, then go in for the third rule. The third rule always succeds since either one of the fluid has a higher mass-flow rate. Rules are written as:

```
( Defprop tube-side-fluid
((( tube-side-fluid  ? name-h)
 (( fluid-name   hot-fluid  ?name-h)
  ( corrosive   ? name-h   ?X)
  (=  ?X   YES))
ST 10)
(( tube-side-fluid  ? name -c)
(( fluid-name cold-fluid ? name-c)
( corrosive  ? name -C  ?X)
(=   ?X   YES))
ST 11)
etc.
```

2.4 WORKING OF THE PRESENT SYSTEM

The heart of this ' Expert System Shell' is the infer algorithm. The system accepts any query when the function goal is used, e.g. if the query is (Area-req ?X)

then (Goal '(Area-req ?X)) will try to satisfy the query. This ' Expert System Shell' has been developed by Dr. R. Sangal, IIT Kanpur.

The infer algorithm takes query and Alist as its argument and does a series of operations as follows:

1. It gets the order of operation for the predicate in the given query. If there is no order of specified, order of operation is taken as (compute-pred Action-pred Facts Rules Question Question proc).

2. It checks whether any properties are stored under the property attributes listed in the order-op one by one.

a. If the predicate has properties under compute predicate, then the arguments are passed on to the compute predicate after substituting for the variables in the arguments of the predicate.

b. A similar procedure is followed in case of action-pred

c. In case of facts, the facts are retrieved by the macro ' GET-FACTS'. A function ' INFER-UNTIL' checks whether the unification succeeds with any of the facts if it does, it returns nil since it cannot have two bindings simultaneously if the context is True, Else the match is obtained from the fact and binding is returned in the Alist.

d. When trying to apply a rule, the antecedent is also just like a list of querries. Each of the query is

to be satisfied and hence the query is changed to a new one from the Antecedent of the rule, and this whole procedure is repeated.

d. The question is printed and the user response is stored as the answer.

The'=' predicate has two meanings in this system First, it takes 2 arguments and

1. If both the arguments are free of variables after ultimate substitution, returns True or False depending upon whether the binding is true or not
2. If any of the argument doesn't have a binding but is a variable, a corresponding binding is created and returned in the ALIST thus returning value of the predicate as True.

CHAPTER 3

METHODOLOGY FOR THE DESIGN OF SHELL AND TUBE HEAT EXCHANGERS

3.1 INTRODUCTION:

Shell and Tube Heat Exchanger (STHE) is a very commonly used heat transfer equipment. It has no moving parts; it simply exchanges heat between two fluids. A general impression about its design is that it is simple and straightforward. Although a STHE is not a sophisticated piece of equipment, yet a large number of considerations enter the design process. If one looks at the petrochemical industry in past 25 years or so, it is seen that this industry has undergone a tremendous change as far as the use of heat exchangers in terms of their number, size and the type, is concerned. It has now become essential for the HE designer to be a specialist. A poor design or an omission of minor details in the design can lead to failures or may involve a heavy cost of repair or replacement of the HE. In this context, the development of the intended 'Expert System' should incorporate the minute design details for the successful functioning of the HE. This Chapter deals with the complete methodology of the design of STHE without phase change.

The design of STHE involves the computations for both the tube and the shell side. The flow through a tube or a bank of tubes is well defined, but that over a bank of baffled tubes having window and manufacturing tolerances is not at all defined. Hence, the tube side calculations can be made relatively easily. For the shell side a large number of methods (Devore, 1961); Dohonue, 1955; Kern, 1950; Short, 1942; Taborek, 1983 and Tinker, 1947, 1958) are available for the determination of pressure drop and the heat transfer coefficient. Owing to the extensive research work by Bell at the University of Delaware, Taborek (1983) has recommended the Bell, Delaware method, as the most suitable one which is used here to develop the expert system. The method is described in detail in Taborek (1983). The standard description of STHE components etc. can also be found in this reference.

3.2 LOGIC OF THE DESIGN METHOD:

The basic criterion that given or designed heat exchanger should satisfy is that it should perform the given heat duty within the allowable pressure drop.

The design process can briefly be summarised in the following 7 steps (Taborek, 1983).

3.2.1 Problem Identification:

STHE are extensively used in the petrochemical process industry, pharmaceutical industry, chemical process

industries just to name a few. The process designer comes up with a thermal problem of exchanging heat between two fluids. He has the inlet as well as outlet conditions known from his process requirement.

3.2.2 Selection (Fanaritis, 1976) :

Selection is the process, in which the designer selects a particular type of heat exchanger for a given application. Selection criteria are many, but primary criteria are type of fluids, operating pressures and temperatures, heat duty, and cost.

There are an almost unlimited number of alternatives for selecting a heat transfer equipment, but only one amongst them is the best for the given set of constraints. STHE are the most widely used type of heat exchangers.

3.2.3 Selection of a Tentative Set of Parameters:

The heat duty in KW, a heat exchanger is required to perform is given by

$$Q_o = \dot{M}_s \, C_{p_s} \, \Delta T_s = \dot{M}_t \, C_{pt} \Delta T_t \qquad \text{....(3.1a)}$$

The heat duty can also be written as

$$Q_o = U_o \, A_o \, F \Delta T_{LM} \qquad \text{...(3.1b)}$$

where

$\dot{M}_s, \dot{M}_t$ = mass flow rates of shell and tube-side fluids

C_{ps}, C_{pt} = specific heats of the shell-and the tube side fluids.

$\Delta T_s, \Delta T_t$ = Absolute temperature differences between the inlet and the exit temperatures for the shell and tube side strems respectively.

A_o = Total heat transfer area

ΔT_{LM} = Log mean temperature difference (LMTD)

F = LMTD correction factor

U_o = Overall heat transfer coefficient

The first step is to determine U_o which is given by

$$U_o = \frac{1}{\left[\frac{1}{h_s} + R_{f_s} + \left(\frac{r_o - r_i}{k_w}\right)\left(\frac{2r_o}{r_o + r_i}\right) + \left(R_{f_t} + \frac{1}{ht}\left(\frac{r_o}{r_i}\right)\right]}$$

where

h_s, h_t = Convective film heat transfer coefficients for the shell-and tube-side fluids.

r_i, r_o = Inner and outer radii of the tube

R_{fs}, R_{ft} = Fouling factors for the shell- and tube-side fluids

k_w = Thermal conductivity of the tube wall material

Since the tube wall thickness is very small, the mean tube area is approximated as the average of outer and inner area.

The film coefficients are assumed for the type of fluids and so are the fouling factors.

The tentative design is prepared based on the assumed values of the film coefficients.

3.2.4 Rating of the Design :

A detailed analysis of the heat transfer and pressure drop for the two process fluids is known as Rating. The Rating program takes the values of flowrates, temperatures and pressures, configuration of the heat exchanger and fluid properties as inputs, and computes the required heat transfer area for the given duty and given type of heat exchanger along with the drop in pressure.

3.2.5 Evaluation:

The rating program gives the values of the actual film coefficients and the pressure drop, for both the streams. If these parameters are acceptable, the design is complete. Mostly, it is found that the required heat transfer area does not match with the available area, or the pressure drop exceeds the permissible value. Under such circumstances, the design has to be modified.

If the design is acceptable one can proceed for the mechanical design and cost estimation.

3.2.6 Modification of the Design Parameters:

The assumed values of heat transfer coefficients seldom comply with the values of film coefficients after rating.

Nomenclature of heat-exchanger components

1 Stationary head—channel
2 Stationary head—bonnet
3 Stationary head flange—channel or bonnet
4 Channel cover
5 Stationary head nozzle
6 Stationary tubesheet
7 Tubes
8 Shell
9 Shell cover
10 Shell flange—stationary head end
11 Shell flange—rear head end
12 Shell nozzle
13 Shell-cover flange
14 Expansion joint
15 Floating tubesheet
16 Floating head cover
17 Floating head flange
18 Floating head backing device
19 Split shear ring
20 Slip on backing flange
21 Floating head cover—external
22 Floating tubesheet skirt
23 Packing box flange
24 Packing
25 Packing follower ring
26 Lantern ring
27 Tie rods and spacers
28 Transverse baffles or support plates
29 Impingement baffle
30 Longitudinal baffle
31 Pass partition
32 Vent connection
33 Drain connection
34 Instrument connection
35 Support saddle
36 Lifting lug
37 Support bracket
38 Weir
39 Liquid level connection

Construction types

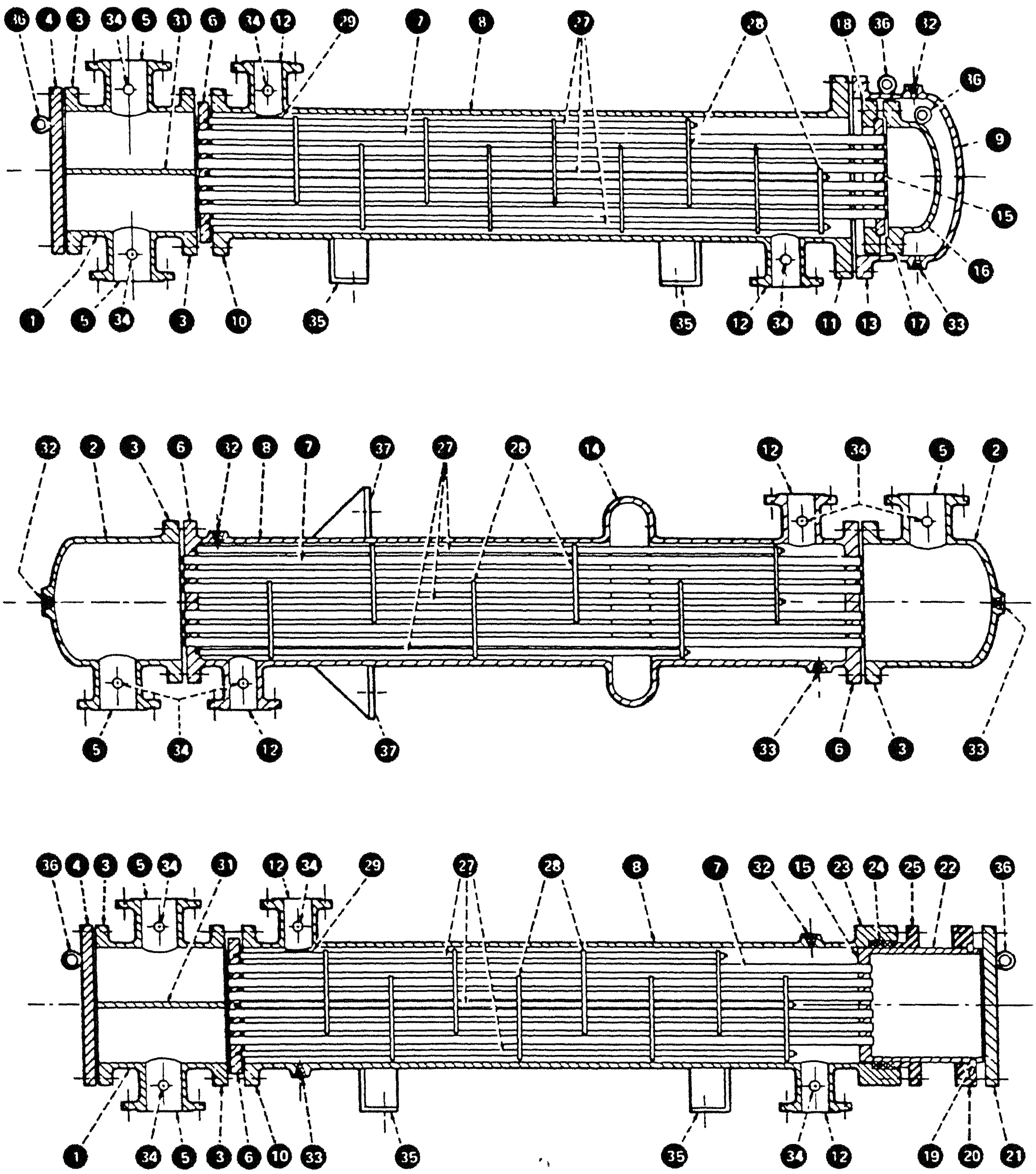


Fig 3.1 Nomenclature for the shell and tube heat exchanger

In this case, the heat transfer area can be decreased or increased as the case may be. Changing the HE dimensions has a remarkable effect on the film coefficients.

The film coefficients can be increased by increasing the flow velocities, changing the baffle spacing, changing the number of tube side passes etc. In an attempt to increase the heat transfer coefficient, the pressure drop also increases.

3.2.7 Mechanical Design and Cost Estimation:

Once the thermal design is complete, the various parts of the heat exchanger are checked for stresses. The costing of the heat exchanger is done only after it is found that stresses in all the parts are within the safe limit.

3.3 APPROXIMATE SIZING OF THE HEAT EXCHANGER:

The basic design equation is

$$A_o = \frac{Q}{U_o \, F \Delta T_{LM}} \qquad \text{.... (3.3)}$$

where Q and U_o are computed from equations (3.1) and (3.2)

T_{LM}, is defined by

1. For a counter-flow HE,

$$\Delta T_{LM} = \frac{(T_{h_{in}} - T_{c_{out}}) - (T_{h_{out}} - T_{c_{in}})}{\ln \left[\frac{(T_{h_{in}} - T_{c_{out}})}{(T_{h_{out}} - T_{c_{in}})} \right]} \qquad \text{... (3.4)}$$

2. For a single shell and tube pass HE mean temperature difference (MTD) is the same as that computed from equation (3.4), hence F=1.0. For HE with 1 shell pass and 2N tube passes, F is given by (Taborek, 1983)

$$F = \frac{e}{(\partial)\ \ln\left[\frac{2-P(1+R-e)}{2-P(1+R+e)}\right]} \qquad \ldots\ldots(3.5a)$$

For a 2 shell pass and 2 tube pass HE, flow is true counter-current hence

$$F = 1.0$$

For a 2 shell pass and 2N tube passes HE, F is given by (Kern, 1950)

$$F = \frac{\frac{e}{2(R-1)} \ln \frac{(1-P)}{(1-PR)}}{\ln\left[\frac{2/P-1-R+(2/p)\sqrt{(1-P)(1-PR)}+e}{2/P-1-R+(2/P)\sqrt{(1-P)(1-PR)}-e}\right]} \qquad \ldots\ (3.5b)$$

where

R = Heat Capacity Ratio

$$= \frac{T_{si}-T_{so}}{T_{to}-T_{ti}} = \frac{\dot{m}_s\ C_{ps}}{\dot{m}_t\ C_{pt}} \qquad \ldots\ (3.6)$$

P = Thermal Effectiveness

$$= \frac{T_{to}-T_{ti}}{T_{si}-T_{ti}} \qquad \ldots\ldots\ (3.7)$$

$$e = \sqrt{R^2 + 1} \qquad \ldots\ldots\ (3.8)$$

T_{si}, T_{so} = Inlet and outlet temperatures for the shell side fluid

T_{ti}, T_{to} = Inlet and outlet temperatures for the tube side fluid

$$\partial = \frac{R-1}{\ln[(1-P)/(1-PR)]} \Big|_{R \neq 1}$$

$$= \frac{1-p}{p} \Big|_{R \rightarrow 1}$$

The MTD is computed as

$$T_M = F \Delta T_{LM} \qquad \ldots . \quad (3.9)$$

3. For computing U_o from equation (3.2) suitable values of h_s, h_t, R_{fs}, R_{ft} are assumed.

4. The total area required is computed using equation (3.3)

5. The surface area, A_o, can be written as

$$A_o = A_o \; (D_s, L_s, D_t, \text{type of pitch lay out}) \qquad \ldots . \quad (3.10)$$

where

D_s = Diameter of the shell

L_s = Length of the shell

D_t = Outside diameter of the tube

The type of pitch layout is characterized by an angle Θ_{tp} shown in Fig. 3.2. The ratio L_s/D_s (Called Aspect Ratio) can lie anywhere between 3.0 to 15.0. Larger value gives a smaller size HE hence economical. Generally an aspect ratio of 8.0 for the shell is remommended . The relation between the heat transfer area, A_o, and other parameters of equation (3.10) is given by

$$A_o = (10^{-6}) \times A^*[L_{ta}\ (D_{ctl})^2] \quad m^2 \qquad \ldots(3.11)$$

where L_{ta} = Length of the tube between two tube-sheets (taken equal to the shell length, L_s, for approximate design)

D_{ctl} = Tube bundle diameter (taken equal to the shell inside diameter, D_s, for approximate design)

A^* is the tube layout density parameter defined as

$$A^* = 0.78\pi\ \left(\frac{1}{C_1}\right) \frac{D_t}{(L_{tp})^2} \quad mm^{-1} \qquad \ldots(3.12)$$

L_{tp} = Tube pitch = 1.25 D_t

C_1 = Tube field layout constant

= 1.0 for $\Theta_{tp} = 45^o$ or 90^o

= 0.866 for $\theta_{tp} = 30^o$

θ_{tp} = Tube layout angle (see Fig.3.1)

The shell diameter ($D_s = D_{ctl}$) and the length ($L_s = L_{ta}$) can be computed from equation (3.11) once the aspect ratio is known.

3.4 SHELL SIDE PARAMETERS:

3.4.1 Shell Dimensions

Knowing L_{ta} and D_s, the shell dimensions can be calculated as follows:

1. Bundle Shell Clearance (L_{bb})

A suitable tube bundle is selected based on the user's requirement and the bundle shell clearance is calculated based upon the equations given below.

a. Bundle type = fixed tube sheet

$L_{bb} = 12.0 + 0.005\ D_s$ mm ....(3.13)

b. Bundle type = U tube sheet

$L_{bb} = 12.0 + 0.005\ D_s$ mm ....(3.13a)

c. Bundle type = Packed Lantern ring

$L_{bb} = 25.0 + 0.0175\ D_s$ mm ....(3.14)

d. Bundle type = Outside packed floating head

$L_{bb} = 25.0 + 0.0175\ D_s$ .... (3.14a)

e. Bundle type = Split backing ring floating head

$L_{bb} = 25.0 + 0.175\ D_s$ mm .... (3.14b)

f. Bundle-type = Pull through floating head

inlet pressure for shell < 1000.0 kPa

$L_{bb} = 80.0 + 0.0325\ D_s$ mm ....(3.15)

inlet pressure for shell $\geq$ 1000.0 kPa

$L_{bb} = 80.0 + 0.0413\ D_s$ mm ....(3.16)

2. Bundle Diameter (D_{ctl}) is computed from the equation

$$D_{ctl} = D_s - L_{bb} \quad \text{....(3.17)}$$

3. Shell Length is taken as the overall nominal tube length, L_{to}, given by

$L_{to} = L_{ta} + 2\ L_{ts}$ ....(3.18)

where

L_{ts} = Tube sheet thickness

$L_{ts} = 0.1\ Ds$, $L_{ts} \geq 25.0$ mm .... (3.19)

3.4.2 Baffle Geometry:

1. Baffle Spacing (L_{bc})-A uniform baffle spacing is assumed initially, equal to D_s-which is used to compute the Number of baffles as

$$N_b = \left(\frac{L_{ta}}{D_s} - 1\right) \qquad \ldots\ldots (3.20)$$

This is rounded off to the lower integer and the exact central baffle spacing is then calculated by

$$L_{bc} = \frac{L_{ta}}{N_b + 1} \qquad \ldots\ldots (3.21)$$

2. Segmental Baffle Cut, B_c, as a percent of D_s.

   The value depends upon the Ratio L_{bc}/D_s and is given by

$$B_c = 16.25 + 18.75\ (L_{bc}/D_s) \qquad \ldots\ldots (3.22$$

3. Centriangle of Baffle Cut (θ_{ds}) is the angle subtended at the center by the intersection of the baffle cut and the inner shell wall, see Fig.3.3). It is given by

$$\theta_{ds} = 2\cos^{-1}\left[1 - 2\left(\frac{B_c}{100}\right)\right] \text{ rad} \qquad \ldots\ldots (3.23)$$

4. Upper Centriangle of Baffle Cut (θ_{Ctl})- is the angle substended at the center by the intersection of the baffle cut and the tube bundle diameter, (see Fig.3.3) It is given by

$$\theta_{ctl} = 2\cos^{-1}\left[\frac{D_s}{D_{ctl}}\left(1 - \left(\frac{2B_c}{100}\right)\right)\right] \text{ rad} \qquad \ldots\ldots (3.24)$$

Tube layout geometry basic parameters

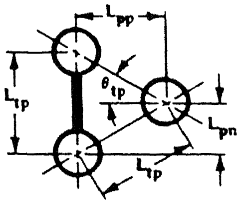
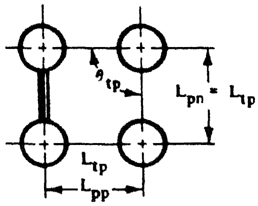
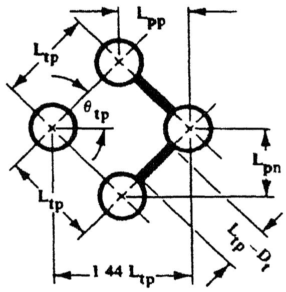
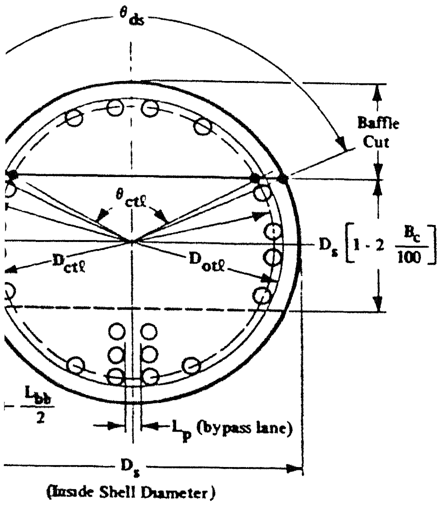
Cross flow →	θ_{tp}	L_{tp}	L_{pp}
	30°	0 5L_{tp}	0 866L_{tp}
	90°	L_{tp}	L_{tp}
	45°	0 707L_{tp}	0 707L_{tp}

Fig 3.2 Pitch layout angle



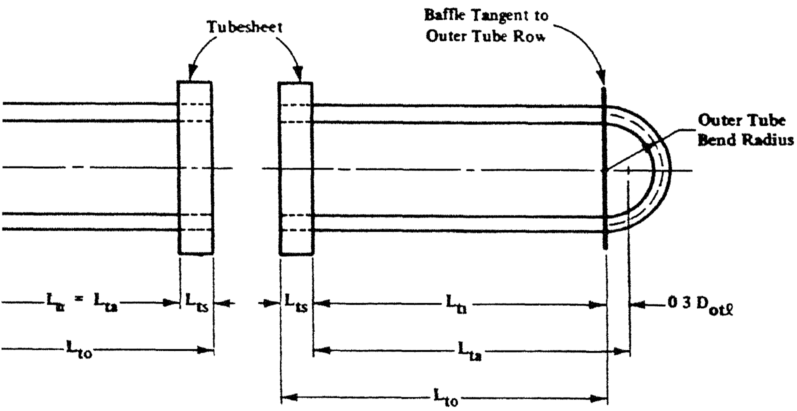


Fig 3.3 Bundle Geometry

3.4.3 Bundle Type (Lord, 1970,~~1970~~ and Kern, 1950):

1. Fixed tube sheet HE has the simplest type of shell design. The tube sheets may be welded or bolted to the shell. Since there are no packings or gaskets involved, this type of HE has the maximum possible protection against leakage of shell side fluid to ambient. The fixed tube-sheet HE does not have any provision to accomodate the differential expansion of the shell and the tubes.

2. Removable Bundle Exchangers:

Shell and Tube Floating Tubesheet

It has straight tubes secured at one fixed end and the other movable end is known as floating tube sheet.

(i) Outside Packed Stuffing Box- The shell side fluid is sealed by rings of packing compressed within a stuffing box by a follower ring. It can be used for pressures upto 2000.0 kPa and temperatures upt 300°C. They are not used when even slightest amount of leakage to the ambient cannot be tolerated.

(ii) Outside Packed Lantern Ring - The shell side and tube side fluids are each sealed by seperate rings of packing seperated by a lantern ring provided with weep holes so that leakage through either of them should be to the outside. Number of tube side passes is limited to one or two. They are used for shell side pressure < 1034. kPa

and temperatures on shell side < 260.0^{o} C . They have a direct advantage that the tubes can be cleaned very easily

(iii) Pull Through Bundle - This type of HE has a seperate head bolted directly to the floating tube sheet. Both the assembled tubesheet and head are small enough to slide through the shell, and tube bundle can be removed without breaking the joints at the floating end .

Though this type has an advantage of very low maintenance time, it accomodates the smallest number of tubes for the given shell diameter and the bundle bypass areas are larger than all other types.

(iv) Inside Split Backing Ring- The inside split backing ring type overcomes the disadvantages of Pull through bundle. It differs from the Pull through type in the use of a split ring assembly at the floating tubesheet and an oversized cover which accomodates it. Clearances between the outermost tubes and the inside of the shell are same as that for outside peaked stuffing box type HE.

3.4.4 Various Flow Areas for the Shell Side Stream:

To compute the correction factors for heat transfer and pressure drop , calculation of various leakage and flow areas is essential.

1. Cross flow area at shell centreline within one baffle spacing , S_m, is given by

$$S_m = L_{bc} \left[L_{bb} + \frac{D_{ctl}}{L_{tp,eff}} (L_{tp} - D_t) \right] \quad \ldots\ldots (3.25)$$

where

$L_{tp,eff}$ = effective tube pitch

$= L_{tp}$ for 30^o and 90^o layout

$= 0.707 \times L_{tp}$ for 45^o layout

2. Baffle Window Flow Areas:

a. Gross window flow area without tubes in the window is given by

$$S_{wg} = \frac{\pi}{4} (D_s)^2 \left(\frac{\theta_{ds}}{2\pi} - \frac{\sin \theta_{ds}}{2\pi} \right) \quad \ldots\ldots (3.26)$$

b. Fraction of number of tubes in the baffle window, F_w, is given by

$$F_w = \frac{\theta_{ctl} - \sin \theta_{ctl}}{2\pi} \quad \ldots\ldots (3.27)$$

c. The fraction of number of tubes in pure cross flow between baffle tips is given by

$$F_c = 1 - 2F_w \quad \ldots\ldots (3.28)$$

d. The segmental baffle window flow area occupied by, N_c, tubes is given by

$$S_{wt} = N_t \, F_w \left(\frac{\pi}{4} D_t^2 \right) \quad \ldots\ldots (3.2()$$

e. The number of tubes in one window is given by

$$N_{tw} = N_t \, F_w \quad \ldots\ldots (3.30)$$

Hence the net cross flow area through one baffle window S_w is

$$S_w = S_{wg} - S_{wt} \qquad \ldots\ldots (31)$$

3. Equivalent Hydraulic Diameter:

The equivalent hydraulic diameter is required only for the pressure drop calculations in laminar flow, i.e. if $R_{es} < 100$. It is calculated from the classical difinition of hydraulic diameter and is given by

$$D_w = \frac{4S_w}{\pi D_t \; N_{tw} + (\pi \; D_s \; \theta_{ds}/2\pi)} \qquad \ldots\ldots (32)$$

4. Number of Effective Tube Rows in Cross Flow:

The determination of effective number of tubes in cross flow is essential for the calculation of heat transfer coefficient and pressure drop, and the corresponding correction factors.

The number of effective tube rows crossed between baffle tips, N_{tcc}, is given by

$$N_{tcc} = \frac{D_s}{L_{pp}} [\; 1-2 \; (\; \frac{B_c}{100})] \qquad \ldots\ldots (3.33)$$

where

L_{pp} = Flow direction distance between 2 tubes

= $0.866 \; L_{tp}$ for $\theta_p = 30^{\circ}$

= L_{tp} for $\theta_p = 90^{\circ}$

= $0.707 \; L_{tp}$ for $\theta_p = 45^{\circ}$

The determination of the number of effective tube rows crossed

in a baffle window, N_{tcw}, depends on the flow pattern. Highest flow velocity exists just below the baffle tips and then decreases rapidly. Finally, the effective distance of cross flow penetration can be determined by

$$L_{wp} = 0.4 \quad [D_s(\frac{B_c}{100}) - \frac{D_s - D_{ctl}}{2}] \qquad \ldots.(3.34)$$

This distance, L_{wp}, is crossed twice in a baffle window, and hence effective number of tube rows crossed is

$$N_{tcw} = \frac{0.8}{L_{pp}} [D_s(\frac{B_c}{100}) - \frac{D_s - D_{ctl}}{2}] \qquad \ldots (3.35)$$

5. Bundle Shell Bypass Area Parameters:

The flow area between the shell inside surface and bundle outside diameter is the main area where flow can bypass the desirable path through the tube field. The flow in this bypass lane can attain considerable order of magnitude (20–30%), thus decreasing heat transfer and pressure drop. The bypass area within one baffle spacing is given by

$$S_b = L_{bc} [(D_s - D_{otl}) + L_{pl}] \qquad \ldots.(3.36)$$

where D_{otl} = Outer diameter of the tube bundle

$$= D_{ctl} + D_t \qquad \ldots.(3.37)$$

L_{pl} = 1/2 of tube lane partition, (mm)

$$= D_t/2 \qquad \ldots. (3.38)$$

For calculations of the correction factors J_l and R_l, the ratio F_{sbp}, of bundle bypass area S_b to the overall cross

flow area S_m is required

$$\therefore \quad F_{sbp} = S_b/S_m \qquad \ldots(3.39)$$

6. Shell to Baffle Leakage Areas:

This area is required for the calculation of the correction factors for baffle leakage effects J_l and R_l. This area calculation involves diametral shell to baffle clearance, given by

$$L_{sb} = 3.1 + 0.004\ D_s \qquad \ldots(3.40)$$

The shell to baffle leakage area is given by

$$S_{sb} = \pi\ D_s\ \left(\frac{L_{sb}}{2}\right)\ \left(\frac{2\pi-\theta_{ds}}{2\pi}\right)\ mm^2 \qquad \ldots.(3.41)$$

7. Tube to Baffle Hole Leakage Area (S_{tb}):

This area is also needed for the calculation of correction factors J_l and R_l. It is given by

$$S_{tb} = \frac{\pi}{4}\ [(D_t+L_{tb})^2-D_t^2) - D_t^2\ ]\ N_t\ (1-F_w) \qquad \ldots..(3.42)$$

where

L_{tb} = Tube to baffle hole clearance

= 0.8 mm for calculations ....(3.43)

3.4.5 Dimensionless Parameters:

1. Shell Side Reynolds Number - The shell side mass velocity is given by

$$\dot{m}_s = \frac{M_s}{S_m} \times (10^{-6})\ kg/m^2\ Sec \qquad \ldots..(3.44)$$

The shell side Reynolds number is given by

$$Re_s = D_t / \dot{m}_s / \eta_s \qquad ..... (3.45)$$

where η_s = Absolute viscosity of the shell side fluid at average shell temperature in centipoise.

2. Shell Side Prandtl Number :

This is given by

$$Pr_s - (C_{ps}\ \eta_s / k_s) \times (10^{-3}) \qquad ..... (3.46)$$

where k_s = Thermal conductivity of the shell side fluid

3.4.6 Correction Factors:

The heat transfer coefficient for ideal cross flow over the tube banks ~~a~~can be readily found out using equation (3.60). In an actual HE, the flow deviates from the ideal case. The various correction factors take into account this deviation. The value of each correction factor lies between 0 and 1 for the ideal case. When all these correction factors are multiplied together with the ideal heat transfer coefficient, one gets the actual heat transfer coefficient. Same holds good for the pressure drop also.

1. Segmental Baffle Window Correction Factor (J_c) - This factor considers the effects of baffle window on heat transfer factor j_i which is based on pure cross flow.

J_c reaches a value of 1.0 for baffle cuts around 25% and even more than 1.0 for smaller baffle cuts. This is

so because of the fact that j_i is computed at the largest cross flows section, but as baffle cut decreases, flow velocities increase. This in turn is compensated by the fact that fewer tubes exist in the baffle window.

The net effect of these is of significance. An approximation of the Delaware method curve is given by,

$$J_c = 0.55 + 0.72\ F_c \qquad \ldots\ldots (3.47)$$

2. Correction Factor for Baffle Leakage for Heat Transfer, J_l, and Pressure Drop, R_l - There is a significant amount of pressure difference between the two adjacent compartments. This pressure differential forces the fluid through two leakage areas- (1) shell and the baffle circumference(2) tube and the baffle tube hole. This decreases the effective cross flow stream and consequently h_s and p_s (total shell side pressure drop). These leakage streams can reach a considerable order of magnitude (40%) and hence are of great importance. Amongst the two leakage streams considered, shell to baffle stream is most detrimental to heat transfer as it does not exchange heat with the tubes.

The tube to baffle leakage stream partially exchanges heat with the tubes hence not as disastrous for the heat transfer.

The following parameters are computed to calculate the heat transfer and pressure drop correction factor:

$$r_{lm} = \frac{S_{sb} + S_{tb}}{S_m} \quad \text{.... (3.48)}$$

and

$$r_s = \frac{S_{sb}}{S_{sb} + S_{tb}} \quad \text{.... (3.49)}$$

The correction factors for heat transfer, J_l, and for pressure drop, R_l, have the following characteristics:

a. Most severe condition occurs for r_s=1,which corresponds to the case of all leakage taking place in the shell to baffle area.

b. The least severe condition corresponds to r_s = 0, when all the leakage is through the tube-baffle holes.

A well designed HE should have values of J_l not less than 0.6. The possible remedies for increasing J_l are:

a. Wider baffle spacing which will shift r_{lm} towards higher value.

b. Increasing tube pitch or changing tube layout to 90° or 45° will also have a similar effect. The correction factors are computed from the following equations:

$$J_l = 0.44\,(1-r_s)+[1-0.44\,(1-r_s)]\exp\,(-2.2\,r_{lm}) \quad \text{.....(3.50)}$$

$$R_l = \exp\,[-1.33\,(1+r_s)\,r_{lm}^{\,p}] \quad \text{.....(3.51)}$$

where $p = [0.15\,(1+r_s)+0.8]$

3. Correction Factors for Bundle Bypass Effects for Heat Transfer, (J_b), and Pressure Drop (R_b) .

The flow resistance along the gap between tube bundle and the shell inner wall is substantially lower than that of the tube field. Naturally, the stream tends to flow through this flow area.

U- tube sheet and fixed tube sheet bundles have a small bundle shell clearance, hence the effect is smaller. In case of pull through bundles, this gap has to be blocked by sealing strips. Sealing strip are used in pairs (on either sides) when L_{bb} exceeds 30.0 mm.

The correction factors J_b and R_b, are given as follows :

$$J_b = \exp\left(- C_{bh} \; F_{sbp} \left[1- (2\, r_{ss})^{1/3}\right]\right) \quad \ldots (3.52)$$

with a limit

$$J_b = 1 \text{ at } r_{ss} \geq 1/2$$

where $C_{bh} = 1.35 \;\ldots\ldots Re_s \leq 100$

$= 1.25 \;\ldots\ldots Re_s \leq 100$

and $r_{ss} = \dfrac{N_{ss}}{N_{tcc}}$

where N_{ss} = no of sealing strip pairs

$$R_b = \exp\left[- C_{bp}\; F_{sbp} \left(1-(r_{ss})^{1/3}\right)\right] \quad \ldots (3.53)$$

where $C_{bp} = 4.5$ for $Re_s \leq 100$

$= 3.7$ for $Re_s \geq 100$

and other parameters have the same meaning as before.

4. Heat Transfer Correction Factor for Adverse Temperature Gradient in Laminar Flow (J_r).

The Delaware data on laminar flow (R_{es}<20) exhibited a large decrease in heat transfer which is eventually postulated as an effect of adverse temperature gradient developed through the boundary layer.

As Re_s increases, momentum change or crtial effects begin to disturb the laminar boundary layer until it almost vanishes at Re_s = 100.

Since the ideal tube banke curves are based on 10 rows of tubes, the corresponding correction factor can be expressed as

$$J_r = \left(\frac{10}{N_c}\right)^{0.18} = \frac{1.51}{(N_c)^{0.18}} \qquad \ldots\ldots (3.54)$$

where N_c = no of tube rows crossed in the HE given by

$$N_c = (N_{tcc}+N_{tcw})\ (N_b+1) \qquad \ldots\ldots (3.55)$$

For $Re_s \geq 20$ to $Re_s = 100$

$$J_r = \frac{1.51}{(N_c)^{0.18}} + \left(\frac{20-R_{es}}{80}\right)\left[\frac{1.51}{(N_c)^{0.18}}-1\right] \ldots (3.56)$$

Minimum valûē of J_r = 0.4

For Rc_s > 100, J_r = 1

5. Correction Factor for Pressure Drop in End Zones:

For equal baffle spacing, this accounts for the pressure drop at the inlet and outlet baffles and is

R_s = 1.3 for U- tube bundles

= 2.0 for other cases ...(3.56a)

3.4.7 Actual Heat Transfer Coefficient on the Shell Side:

This method is based on j_i and f_i factors from the data on ideal tube bank. The ideal tube bank factor is written as

$$j_i = j_i \left(Re_s, \frac{L_{tp}}{D_t}\right)$$

For a fixed value of L_{tp}/D_t = 1.25, the fitted equations for j_i are

$$\theta_{tp} = 30^o \text{ staggered}$$
$$j_i = 10^{[0.0533\, x^2 - 0.7965\, x + 0.1999]} \quad ....(3.57)$$

$$\theta_{tp} = 45^o \text{ staggered,}$$
$$j_i = 10^{[0.0576\, x^2 - 0.8282\, x + 0.3]} \quad ....(3.58)$$

$$\theta_{tp} = 90^o \text{ inline,}$$
$$j_i = 10^{[0.05386\, x^2 - 0.75432\, x]} \quad ....(3.59)$$

where $x = \log_{10}(Re_s)$

The ideal tube bank heat transfer coefficient then becomes,

$$h_{s_{ideal}} = j_i\, C_{ps}\, \dot{m}_s\, (Pr_s)^{-2/3}\, (\phi_s)^r \quad ....(3.60)$$

where j_i is determined from one of the equations given qbove.

$(\phi_s)^r$ = viscosity correction factor that accounts for the viscosity gradient at the tube wall versus the viscosity

at the average bulk fluid temperature, η_s. The term $(\phi_s)^r$ is computed as follows:

1. For liquids -

$$(\phi_s)^r = \left(\frac{\eta_s}{\eta_{sw}}\right)^{0.14} \qquad \ldots\ldots (3.61)$$

where η_{sw} is the shell fluid viscosity determined at the tube wall temperature, T_w.

$\phi_s > 1.0$ for shell fluid heated

and $\phi_s < 1.0$ for shell fluid cooled.

In order to determine η_{sw}, it is essential to determine T_w which is estimated as follows using the approximate values of h_t and h_s

$$T_w = T_{t_{av}} + \left(\frac{T_{s_{av}} - T_{t_{av}}}{1+(h_t/h_s)}\right) \qquad \ldots\ldots (3.62)$$

where $T_{s_{av}}$, $T_{t_{av}}$ denote the average shell and average tube temperatures, both of them being the arithmetic means of inlet and outlet temperatures respectively. It may be noted from equation (3.62) that the tube wall temperature approaches the temperature of the fluid with higher 'h'.

If viscosity of the fluid is known at two temperatures other than T_w and $T_{s,av}$, a relation of the from

$$\eta = aT^b \qquad \ldots. (3.63)$$

can be used for extrapolating the viscosity within reasonable temperature limits. The temperature, T in equation (3.63)

is in degree Kelvin. Once, η_s and $\eta_{s,w}$ are known, $(\phi_s)^r$ can easily be computed.

2. For gases, the viscosity is a weak function of temperature and the correction factor is formulated as

For gas being cooled : $(\phi_s)^r = 1.0$ .... (3.64)

For gas being heated : $(\phi_s)^r = \left(\frac{T_{s_{av}} + 273.15}{T_w + 273.15} \right)^{0.25}$ .... (3.65)

for a gas being heated, T_w is always higher than $T_{s,av}$ and hence $(\phi_s)^r < 1.0$

The actual heat transfer coefficient is calculated as

$$h_s = h_{s\ ideal} \ (J_c \cdot J_l \cdot J_b \cdot J_r) \qquad \text{.... (3.66)}$$

3.4.8 Shell Side Pressure Drop (ΔP_s):

The shell sid(pressure drop is composed of three distinct components, Δp_c for pure cross flow, ΔP_w for all baffle windows and Δp_c for end zones. Total pressure drop

$$\Delta p_s = \Delta p_c + \Delta p_w + \Delta p_c \qquad \text{.....(3.66a)}$$

1. Ideal Tube Bank Pressure Drop :

The ieal tube bank friction factor is given by

$$f_i = (10^3) \ \frac{(\Delta p_{bi}) \ \rho_s}{2(\dot{m}_s)^2 \ N_c} \ (\phi_s)^r \qquad \text{....(3.67}$$

$$= f \ (Re_s)$$

The fitted equations for f_i are

$$\theta_{t_p} = 30^\circ,$$

$$f_i = 10^{[0.01745\ x^2 - 1.1516\ x + 2.162]} \quad \ldots (3.68)$$

$$\theta_{t_p} = 45^\circ,$$

$$f_i = 10^{[0.01535\ x^2 - 1.362\ x + 1.821]} \quad \ldots (3.69)$$

$$\theta_{t_p} = 90^\circ$$

$$f_i = 10^{[0.099089\ x^2 - 0.9826\ x + 1.2852]} \quad \ldots . (3.70)$$

where $x = \log_{10}(Re_s)$

The ideal tube bank pressure drop is readily computed as

$$\Delta p_{bi} = 2 \times 10^{-3} x f_i x\ N_{tcc} x\ \frac{(\dot{m}_s)^2}{\varrho_s} (\phi_s)^{-r} \quad \ldots . (3.71)$$

where, ϱ_s = density of shell side fluid, kg/m^3.

2. Pressure Drop in Pure Cross Flow $_{pc}$ is given by

$$\Delta pc = \Delta p_{bi}\ (N_b - 1)\ (R_b)\ (R_i) \quad \ldots . (3.72)$$

3. Pressure Drop in All the Baffle Windows Crossed (P_w):

Mass velocity based on geometric mean of the cross flow area S_m is given by

$$\dot{m}_w = \frac{\dot{M}_s}{\sqrt{S_m S_w}} \times 10^6 \text{ kg/m}^2 \text{ Sec} \quad \ldots . (3.73)$$

The pressure drop in all windows crossed, P_w is given by

for $Re_s \geq 100$,

$$\Delta P_w = N_b \left(\frac{26(\dot{m}_w)\eta_s}{\rho_s}\left[\frac{N_{tcw}}{L_{tp}-D_t} + \frac{L_{bc}}{(D_w)^2}\right] + \left[2\times10^{-3}\frac{(m_w)^2}{2\rho_s}\right]\right) R_{es} \,..\, kPa \quad .....(3.75)$$

4. Pressure Drop in the End Zones is given by:

$$\Delta P_c = \Delta P_{bi}\left(1+\frac{N_{tcw}}{N_{tcc}}\right) R_b\, R_s \quad .....(3.75a)$$

3.5 Tube Side Parameters (Kern, 1950):

3.5.1 Tube Side Passes:

The number of tube side passes is determined on the basis of the flow velocity in the tubes. The flow velocity should be between 1.0 to 3.0 ms^{-1}. The lower limit is to overcome fouling and the upper one to reduce corrosion and vibration. The total flow area available is given by

$$A_{tot} = \frac{\pi}{4} \times (D_t - t_t)^2 \times N_t \quad ......(3.76)$$

The area per pass required to maintain a velocity v_t through the tubes is given by

$$A_{t_p} = \frac{\dot{M}_t \times 10^6}{\rho_t\, v_t} \quad ......(3.77)$$

where,

t_t = thickness of the tubes, mm

ρ_t = density of tube side fluid, kg/m^3

The number of tube side passes are

$$N_{tp} = \text{Integer}\left(\frac{A_{tot}}{A_{tp}}\right) \quad ......(3.78)$$

3.5.2 Total Number of Tubes is given by:

$$N_t = \frac{0.78\ D_{ctl}^{2}}{C_l (L_{tp})^2} \qquad \text{......} \; (3.79)$$

where C_l = tube layout constant

for θ_p = 30^o, C_l = 0.866

for θ_p = 45^o and 90^o, C_l= 1.0

3.5.3 Mass Velocity in Tubes is given by

$$\dot{m}_t = \frac{\dot{M}_t x 10^6}{(A_{tot}/N_{tp})} \qquad \text{.......} (3.81)$$

3.5.4 Tube Side Reynolds Number (Re_t):

$$Re_t = \left(\frac{(D_t - t_t)\dot{m}_t}{\eta_t}\right) \qquad \text{.......} (3.82)$$

where η_t = viscosity of the tube side fluid, at average tube temperature, cp,

3.5.5 Tube Side Prandtl Number (P_{r_t})

It is given by

$$Pr_t = \left(\frac{C_{pt}\eta_t}{k_t}\right) x\ 10^{-3} \qquad \text{......} \; (3.83)$$

where k_t = Thermal conductivity of tube side fluid.

3.5.6 Actual Tube Side Heat Transfer Coefficient, h_t

Sieder and Tate's relation gives

$$\frac{h_t D}{k} = 1.86 \left(\frac{4}{\pi} \frac{w_c}{kL} \right) \left(\frac{\eta_t}{\eta_w} \right)^{0.14} \quad Re_t \leq 2100 \quad .... (3.84)$$

$$\frac{h_t D}{k} = 0.027 \, (Re_t)^{0.8} (Pr_t)^{1/3} \, (\phi)^{0.14} \quad Re_t > 2100 \quad .....(3.85)$$

The heat transfer coefficient is computed from the j_h curves,

$$j_h = 10^{[-0.2624 \, x^2 + 3.273 \, x - 7.412]} \quad .....(3.86)$$

where $x = \log_{10}(Re_t)$

The actual heat transfer coefficient is then given by

$$h_t = j_h \frac{k_t}{D_t} \, (Pr_t)^{1/3} \, (\phi)^r \quad ......(3.87)$$

where $(\phi)^r$ is to be computed for the tube side fluid in a manner similar to section 3.3.7.

3.5.7 Tube Side Pressure Drop:

1. Tube side friction factor is given by Sider and Tate's correlation for fluids being heated or cooled, in form of a graph (Kern, 1950).

A straight line fitted to the graph is for $Re_t \leq 1000$,

$$f_t = 144 \left(10^{(-Log_{10}(Re_t)-0.3)} \right) \quad .....(3.88)$$

and for $Re_t > 1000$,

$$f_t = 144 \left(10^{[-0.25 \, (Log_{10}(Re_t))-2.55]} \right)$$

2. The Total Pressure Drop is Composed of 2 parts, viz, the pressure drop inside the tubes, p_t and the pressure drop, p_r, associated with the change of direction in the tube side passes. These are given by

$$\Delta p_t = \frac{f_t(\dot{m}_t)^2 L_{ta} N_{tp}}{2.0 \times \rho_t \times (D_t - t_t) (\phi_t)^r} \quad \text{..... (3.89)}$$

and
$$\Delta p_r = \frac{4 \times N_{tp} \times (\dot{m}_t)^2}{2.0 \times \rho_t} \quad \text{......(3.89a)}$$

$$= 4 \times \text{velocity head per pass}$$

where N_{tp} = No of tube side passes,

The total tube side pressure drop is

$$\Delta P_{total} = \Delta P_t + \Delta P_r \quad \text{......(3.89b)}$$

3.6 The Actual Overall Heat Transfer Coefficient U_o is computed from equation (3.2) and using the values for h_s and h_t from equation (3.66) and equation (3.87) respectively. Using this value of U_o, The actual area required for the heat transfer is obtained from

$$(A_o)_{req} = \frac{Q_o}{U_o \; F \; (LMTD)} \quad \text{...... (3.90)}$$

Area required should always be less than the area available, while the pressure drops on the shell side and tube side are within the permissible limits. A well designed HE should be able to perform the heat duty by fully utilizing the allowable pressure drop on shell and tube sides.

CHAPTER 4

RULE SETS FOR THE EXPERT SYSTEM

4.1 FLOW CHART FOR THE DESIGN :

The overall design process of the STHE is quite complicated and lengthy, hence it was necessary to break down this process into distinct blocks and develop the system accordingly. The main blocks identified were, (Refer Fig. 4.2)

1. Approximate design
2. Evaluation of geometric parameters
3. Correction factors for heat transfer and pressure drop
4. Actual shell side heat transfer coefficient
5. Total shell side pressure drop
6. Actual tube side heat transfer coefficient
7. Tube side pressure drop
8. Comparison of the results and iteration

The flow chart and the tree structure is presented in Fig. 4.2 and 4.4 respectively. Flow chart is the representation of transfer of control whereas the tree structure is the structure generated in trying to satisfy the querries to acheive the goal.

4.1.1 Detailed Analysis of Approximate Design:

The approximate design is a tentative set of heat exchanger parameters and if the design is accepted

after rating then this becomes the final design. This step can be further broken down into (Refer Fig.4.1)

(i) Compute overall heat transfer coefficient

(ii) Compute heat rate required

(iii) Compute the area of heat transfer required

(iv) Design the geometry

To compute the overall heat transfer coefficient , we need a tentative set of film coefficients. The film coefficients can be selected based on the type of the fluid. Since the approximate film coefficients for different type of fluids are known, we can store these values as facts. The overall heat transfer coefficient requires determination of shell side and tube side fluid.

At this point we should take the decision regarding the type of data structure we are going to use.

Here there can be two types i.e. for different properties like inlet temperature, outlet temperature, specific-heat, density etc, for both the fluids

```
(A)   (fluid-1      density                 <val>)
      (fluid-1      inlet temperature       <val>)
      (fluid-1      outlet temperature      <val>)

(B)   (density      fluid-1                 <val>)
      (inlet temperature  fluid-1           <val>)
      (outlet-temperature fluid-1           <val>)
```

Type A is centred around the fluids (fluid-1, fluid-2, etc.) while type B is centred around the properties (density, inlet temperature etc.) . Since there are a small number of fluids viz,2 type A has the advantage that the questions, explanations etc. are reduced in number. But at the same time, it reduces the flexibility of asking different questions, and also giving different explanations. The data structure type B does not have such drawback since each question and explanation can be different for each property. It also has another advantage that we can refer to fluid-1 and fluid-2 as shell-side-fluids and tube-side-fluids.

Once the data for the fluids is known, the overall heat transfer coefficient is computed. Computing heat rate is a straightforward process. The area of heat transfer required is a function of heat rate, Log mean temperature difference, overall-heat transfer coefficient and LMTD correction. Once the area is known, we have a choice as there can be any combination of shell diameter and shell length for the given heat transfer area . This problem can be solved by either keeping the aspect ratio fixed or keeping the shell diameter fixed. For the given shell diameter and length, we have a set of rules for designing the different components and parameters of the heat exchanger. The heat exchanger geometry should be modified to accomodate the various process constraints. This concludes the first step in design process.

2. After this brief discussion about the various steps involved in the approximate design, we shall see the actual predicates, actual rules and actual facts used in this system.

a. The aim is to determine the shell diameter and shell length for the given heat duty.

```
ST43: (Shell-Diameter   ?D-S) <--- (Area-Zero     ?A-O),
      ( Area-*    ?A-*), (Aspect-Ratio  ?L-By-D),
      ( =  ?D-S  (**  (* times  (*Quo  ?A-O  ?A-*)
                                (*Quo 1000000.0 ? L-By-D))
                0.333))
```

We can get the value of Aspect Ratio from the user by issuing him a question . If he doesn't specify the value, a value of 8.0 is assumed.

b. Area-zero is computed from the rule

```
ST21: (Area-zero    ?A-O) <---- ( Overall-HTC    ?U-O),
      (Log-Mean-Temp-Diff    ?LMTD),  (Heat-rate    ?Q ),

      (= ?A-O   (*Quo  ?Q  ( * times  ? U-O  ? LMTD)))
```

c. Overall-HTC has the following rule

```
ST16: (Overall-HTC  ?U-O) <---- ( Tube-side-fluid   ?Tube-fluid)
      (Shell-side-fluid  ? shell-fluid),
      (Fluid-type  ?Tube-fluid  ?Type-T),
      (Fluid-type  ?Shell-fluid ?Type-S),
```

```
(Radius-Inside   ? R-I), (Radius-Outside  ?R-O),
(App-film-foul   ? Type-S  ? H-S   ? R-F-S),
(App-film-foul   ? Type -t  ?H-T    ?R-F-T),
(= ?U-O
   (*Quo 1.0 (+ (*Quo  ?1.0   ?H-S)  ?R-F-S
                (*times  (*Quo 0.0025 ? wall-cond)
                         (*Quo (*Times 2.0 ? R-O)
                               (*Plus ? R-O  ?R-I)))
                (*times (* Plus  ?R-F-T (*Quo 1.0 ?H-T))
                        (*Quo    ?R-O  ?R-I)))))
```

d. The shell side fluid is determined by

```
ST3:  (Shell-side-fluid ?Name-c ) <---  (fluid-name cold-fluid
            ? name- c),
      (Fluid-name hot fluid  ? name -h),
      (Tube-side-fluid    ? name-h)

ST4:  (Shell-side-fluid   ?name-h) <---

            (Fluid-name Cold-fluid  ? name-c),
      (Fluid-name   hot-fluid   ? name -h) ( Tube-side-fluid
            ? name-C).
```

The shell-side-fluid has 2 rules, ST3 and ST4.

The queries for fluid-name are satisfied by asking question.

e. The tube-side-flui has the following rules:

```
ST5:  (Tube-side-fluid   ? name-h) <---
      (Fluid-name   hot-fluid  ?name-h),  (corrosive
            ?name-h  ?X),
       (IS-yes   ?X).
```

ST7: (Tube-side-fluid ?name-h) ⟵
(Fluid-name hot-fluid ?name-h), (fouling
?name-h ?X),
(is-yes ?X)

ST9: (Tube-side-fluid ?name-h) ⟵
(Fluid-name hot-fluid ?name-h),
(Fluid-name cold-fluid ?name-c)
(Mass-flow-rate-cold ?name -c ?X),
(Mass-flow-rate-hot ?name- h ?Y)
(> ?Y ?X)

and similar rules for the cold-fluid. These rules are checked one by one. The rule ST5 states that if the hot fluid is corrosive, then it should be placed on the tube-side. The predicate is-yes checks whether the argument is 'yes' or not .

Rule ST7 states if the hot fluid is fouling, then it should be placed on the tube side. The rule ST9 states that the tube-side has the fluid with the higher mass -flow-rate. Similar rules exist for the cold-fluid. It can be seen that the either of the rule ST9 or ST10 matches since some fluid will have mass-flow-rate higher than the other. At this step we infer the tube-side-fluid. When step c is complete, the new query is step d. This is also inferred since the tube-side-fluid is known. We then arrive at step c. The first two queries of the Antecedent are know. 3rd and 4th queries are satisfied by asking questions. This question asks the user to classify the hot and cold fluids in any one of the

given type. Queries 5 and 6 are satisfied by the rules, which require tube diameter and tube wall thickness. Tube Diameter and Tube-wall thickness are known from the question. Queries 7 and 8 are inferred from facts. The app-film-foul predicate has values of the approximate heat transfer coefficient and fouling factor for different types of fluids, stored as facts . After getting the various parameters, U_o is computed. The next query is Log-mean-temp-diff at state b.

f. Log-men-temp-diff has the following rule.

```
ST23: (Log-men-temp-diff    ?LMTD) <---
      (Fluid-name   hot-fluid   ?name-h),
      (Fluid-name   cold-fluid  ?name -c),
      (Inlet-temp.  ?name-h  ?TH-I),
      (Inlet-temp.  ?name-c  ?TC-I),
      (Outlet-temp. ?name-h  ?TH-O),
      (Outlet-temp. ?name-c  ?TC-O),
      (=  ?LMTD (*Quo   (*Dif  (*Dif  ?TH-I  ?TC-O)
                               (*Dif  ?TH-O  ?TC-I))
                        (Log   (*Quo  (*Dif  ?TH-I  ?TC-O)
                                      (*Dif  ?TH-O  ?TC-I)))))
```

The fluid-name, Inlet-temp and outlet-temp are satisfied by asking questions. LMTD is computed from the equation.The next query at stage b is heat-rate .

g. The rule for heat-rate is

```
ST22: (heat-rate  ?Q) <---
      (Fluid-name   cold-fluid  ?name -c),
      (Mass-flow-rate-cold    ?name-c   ?M-c),
      (Specific-heat   ?name-c   ?CP-c)
      (Inlet-temp.     ?name-c   ?TC-I),
      (Outlet-temp.    ?name-c   ?TC-O),
      (=  ?Q  (*   ?M-c   ?CP-c  (*Dif   ?TC-I    ?TC-O)))
```

The first 5 queries are satisfied by asking questions to the user, in the previous steps. At this stage, the variables get the values directly from the ALIST. The heat-rate is computed from the equation given. Remembering that at stage b, we had to satisfy the subqueries at stage f and g, we observe that the Area-zero can be computed by the given equation, concluding step b.

We move upwards at stage a. The first query is already satisfied at stage b. The next query is (Area-* ? A-*).

h. Area-* has the following rule

```
ST19: (Area-*    ?A-*) <---
      (Pitch-layout   ? Type),
      (Constant-of-pitch-layout   ?Type  ?CPL),
      (Tube-diameter   ?D-T), ( Tube-pitch  ?L-TP),
      (=  ?A-*  (*  2.45   (*Quo   1.0   ? CPL)
                  (*Quo   ?D-T  (Square   ?L-TP))))
```

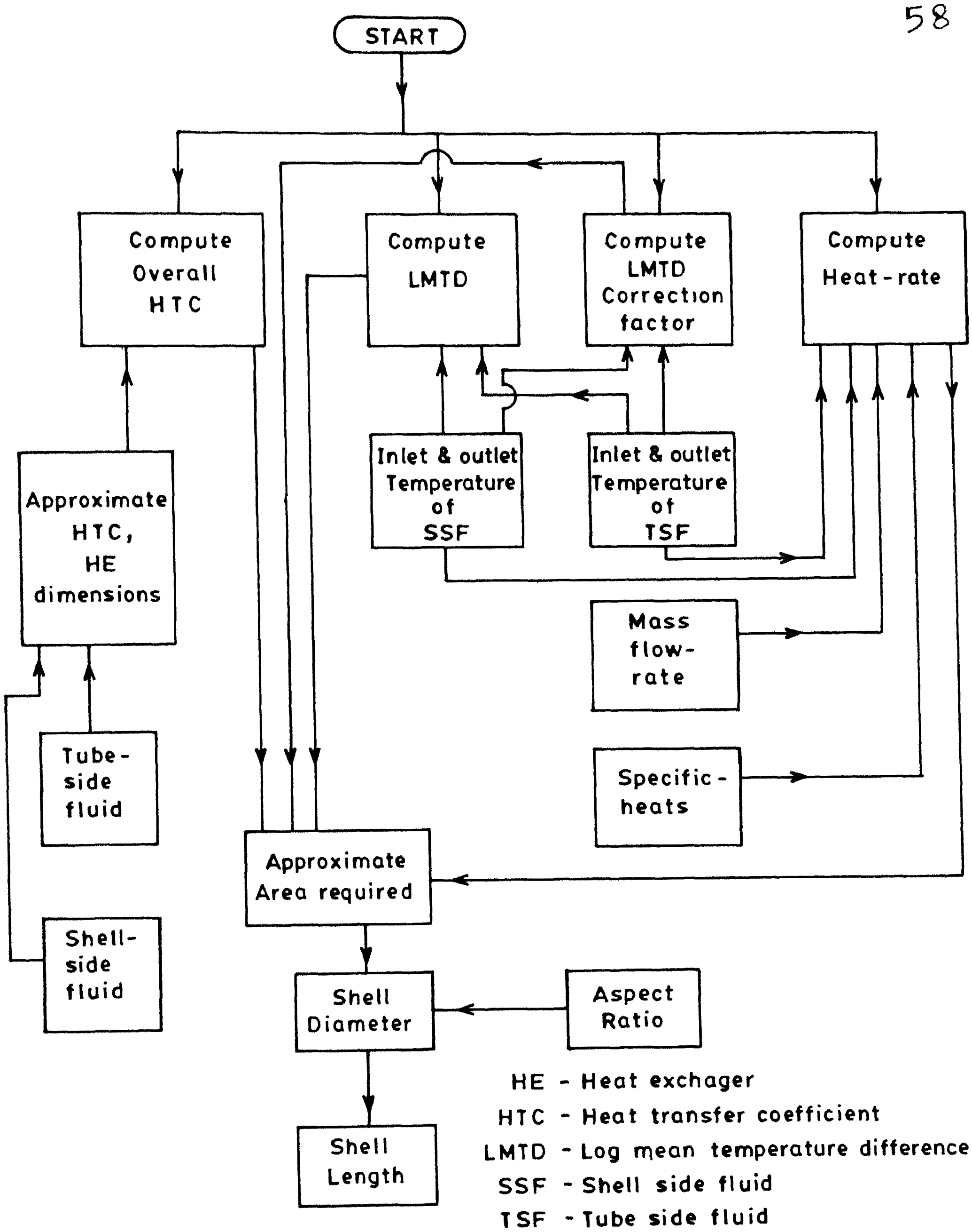


Fig. 4.1 Flow chart for approximate design of STHE .

The pitch-layout is decided by asking question pertaining to pressure-drop and mechanical-cleaning. Staggered-30 type of layout gives a higher pressure drop and mechanical cleaning is difficult. Staggered-45 has ease in mechanical-cleaning. Inline-90 is preferred for low-pressure-drop. The constant of-pitch-layout has facts stored for each one of the 3 pitch-layout-types. Tube-Diameter is known by asking question. The tube pitch is computed as 1.25 times the tube-diameter by Rule no. ST20.

ST20: (Tube-pitch ?L-TP) $\longleftarrow$
(Tube-Diameter ?D-T), (= ?L-TP (* times 1.25 ?D-T)).

Area-* is computed from the equation. We move to the next query (Aspect-Ratio ? L-By-D) at the stage a. Aspect-Ratio is known by issuing a question. Hence the shell-diameter at stage a is inferred.

j. Once the shell-diameter is inferred, the shell-length is computed by rule

ST145: (Shell-length ?L-TA) $\longleftarrow$
(Aspect-ratio ?L-By-D), (Shell-Diameter ? D-S),
(= ? L-TA (*times ?L-By-D ?D-S)).

The above steps can be easily summarised in the flow-chart fig.4.1.

Proceeding in the same way, the further rules were written. The remaining steps are described in short in the following sections. The detailed flow chart for the entire design process is given in Fig. 4.3.

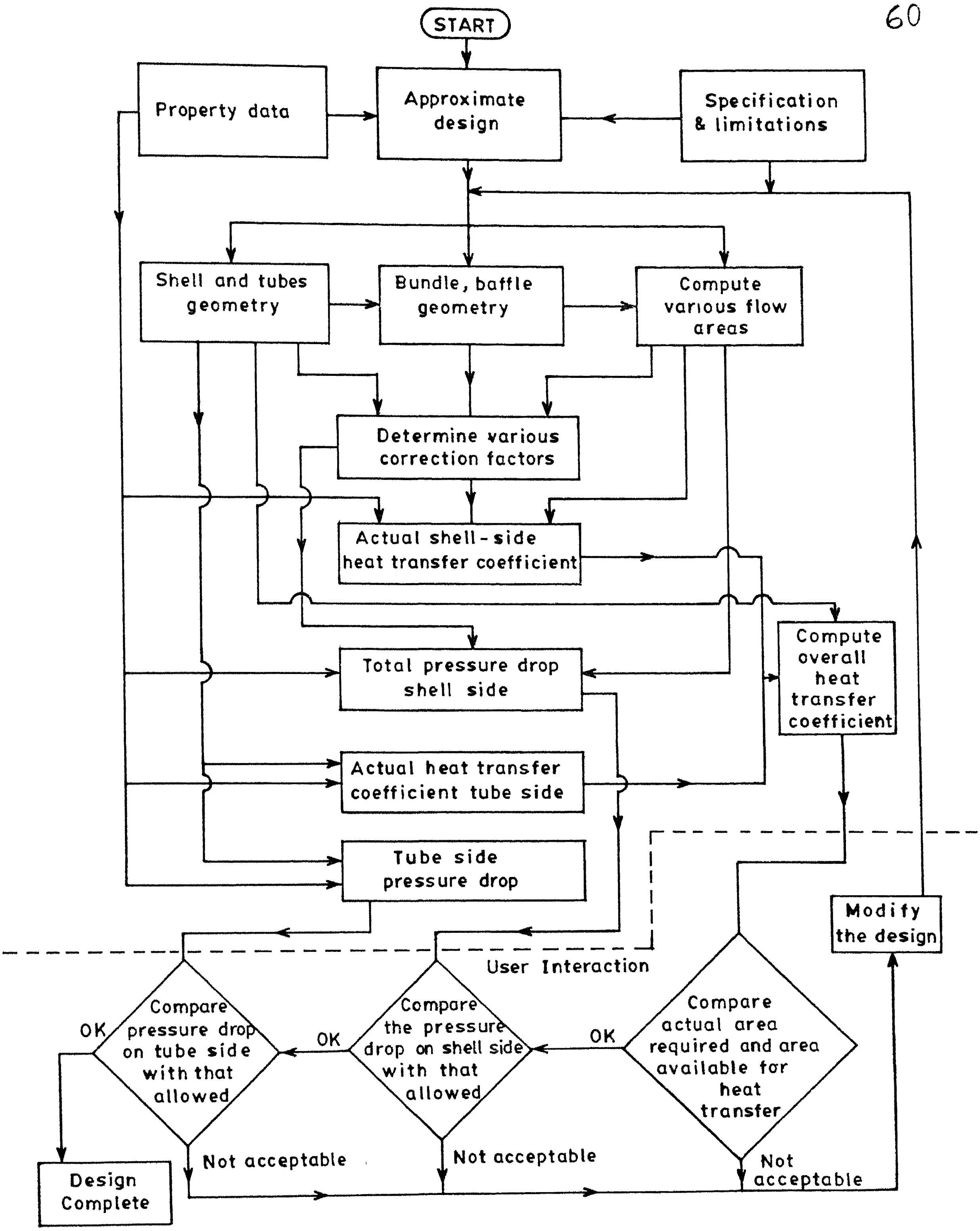


Fig. 4.2 Flow chart for the design of STHE.

4.1.2 The second step is the evaluation of geometric parameters (more detailed than earlier). Geometric parameters mean various flow areas, centriangle of baffle cut etc. These parameters are required for determining the correction factors for heat transfer and pressure drop. The basic dimensions of the tube are supplied by the user. The shell dimension are computed in the step 1 and at step 2, we have 3 further steps as

(i) Determine shell and tube geometry.

(ii) Determine baffle and bundle geometry.

The evaluation of bundle geometry requires determining the bundle type. Bundle type is selected from the inlet condition of the fluids and as well as users requirement.

Baffle cut is a function of shell diameter as well as central baffle spacing. The percentage of baffle cut determines the window correction factor.

(iii) Determine the various flow areas for computing the correction factors.

4.1.3 Determining various correction factors:

There are methods available to compute the heat transfer coefficient and pressure drop for tube banks in pure cross flow. Since in the actual HE the flow is not pure cross flow, a measure of deviation from the cross flow is given by the correction factor.

4.1.4 Actual shell side heat tranfer coefficient can be easily computed once the correction factors and ideal tube bank heat transfer coefficient is known.

4.1.5 Total shell side pressure drop is composed of 3 distinct parts and is computed as a sum of the three pre-ssure drops (a) pressure drop in baffle windows (b) press-ure drop in cross flow and (c) pressure drop in end zones.

4.1.6 Actual tube side pressure drop involves computing Reynolds number and Viscosity correction factor as the main steps. The tube side Reynolds number depends upon the velocity of the tube side fluid which in turn depends upon the no of tube side passes.

4.1.7 Tube side pressure drop is computed after computing the Reynold number and the firction factor.

4.1.8 Comparision of the results and iteration is the step which deals with modifications in the design. The process from step 1 to step 7 can be termed as one cycle. At this stage the user decides whether the design is acceptable or not. The design for which the heat transfer area required is less than the area available within the permi-ssible pressure drop is an acceptable design. The greater the difference between area required and area available, or between the pressure drop permissible and the actual pressure drop, poorer is the design. Such a design needs modification.

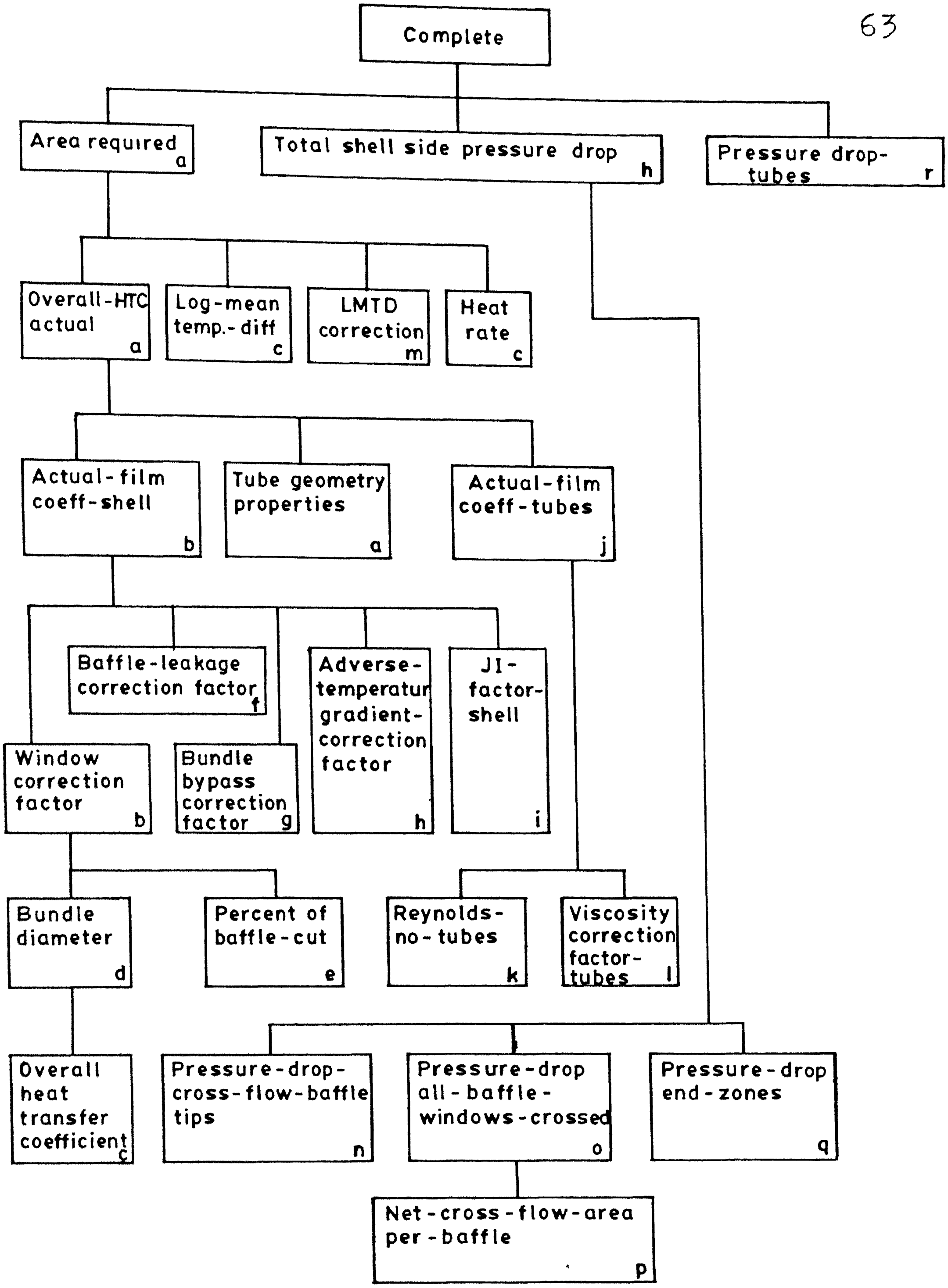


Fig. 4.3 Tree structure for the design of STHE .

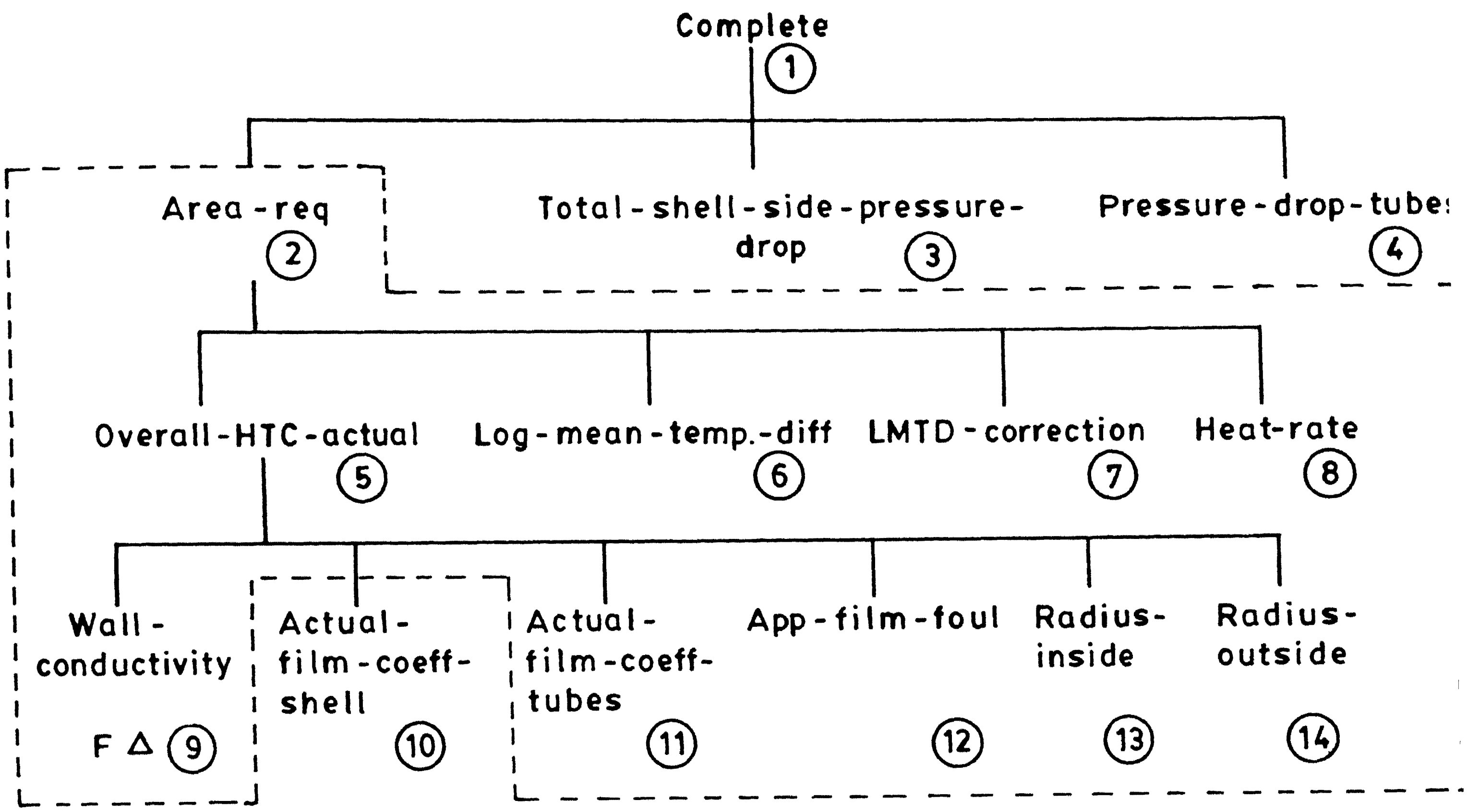


Fig. a

Δ - Value of the predicate argument(s) is known

Q - Question

F - Fact

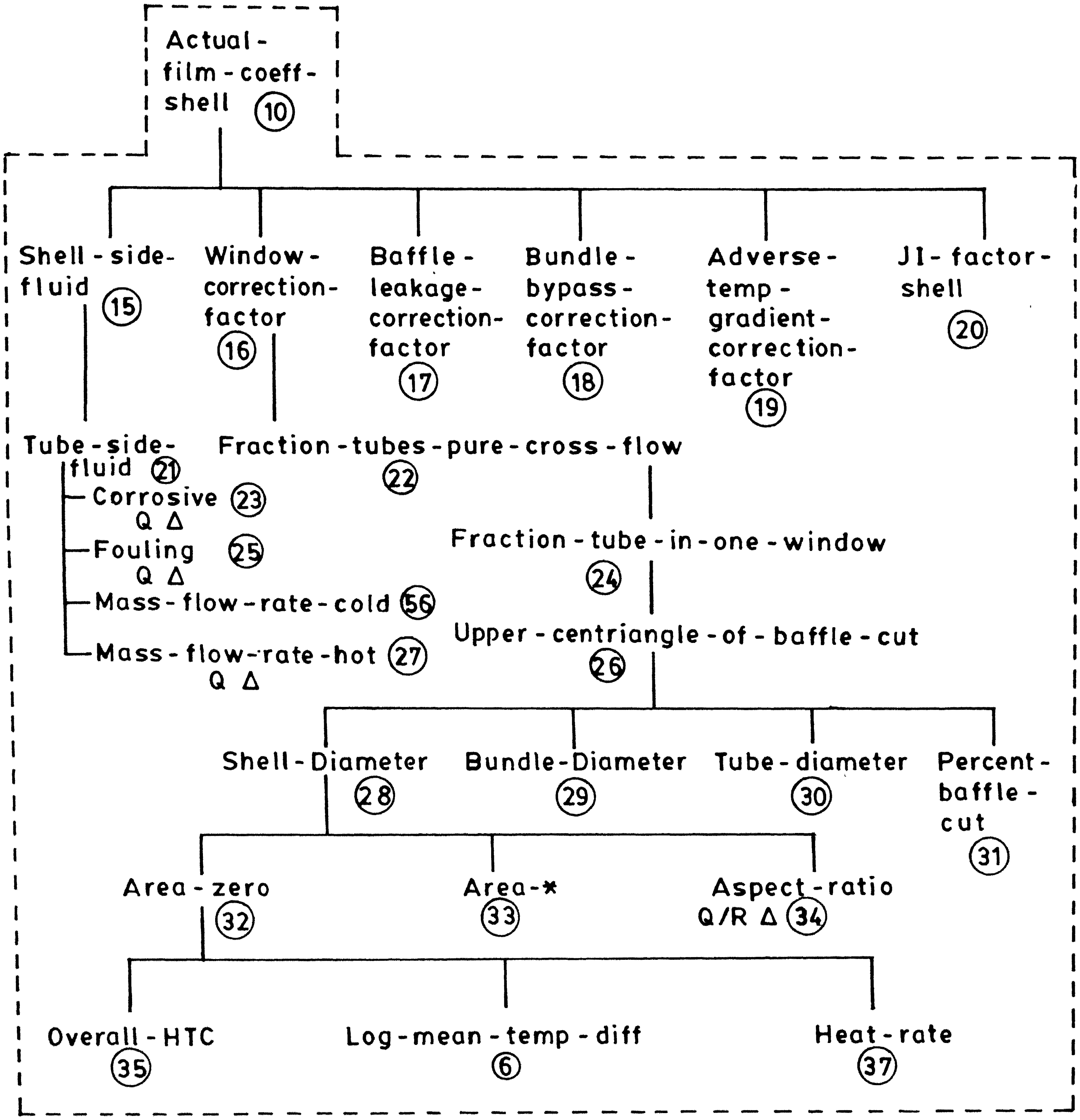

Actual-film-coeff-shell 10
Shell-side-fluid 15
Window-correction-factor 16
Baffle-leakage-correction-factor 17
Bundle-bypass-correction-factor 18
Adverse-temp-gradient-correction-factor 19
JI-factor-shell 20
Tube-side-fluid 21
Corrosive 23
Q Δ
Fouling 25
Q Δ
Mass-flow-rate-cold 56
Mass-flow-rate-hot 27
Q Δ
Fraction-tubes-pure-cross-flow 22
Fraction-tube-in-one-window 24
Upper-centriangle-of-baffle-cut 26
Shell-Diameter 28
Bundle-Diameter 29
Tube-diameter 30
Percent-baffle-cut 31
Area-zero 32
Area-* 33
Aspect-ratio
Q/R Δ 34
Overall-HTC 35
Log-mean-temp-diff 6
Heat-rate 37

Fig. b

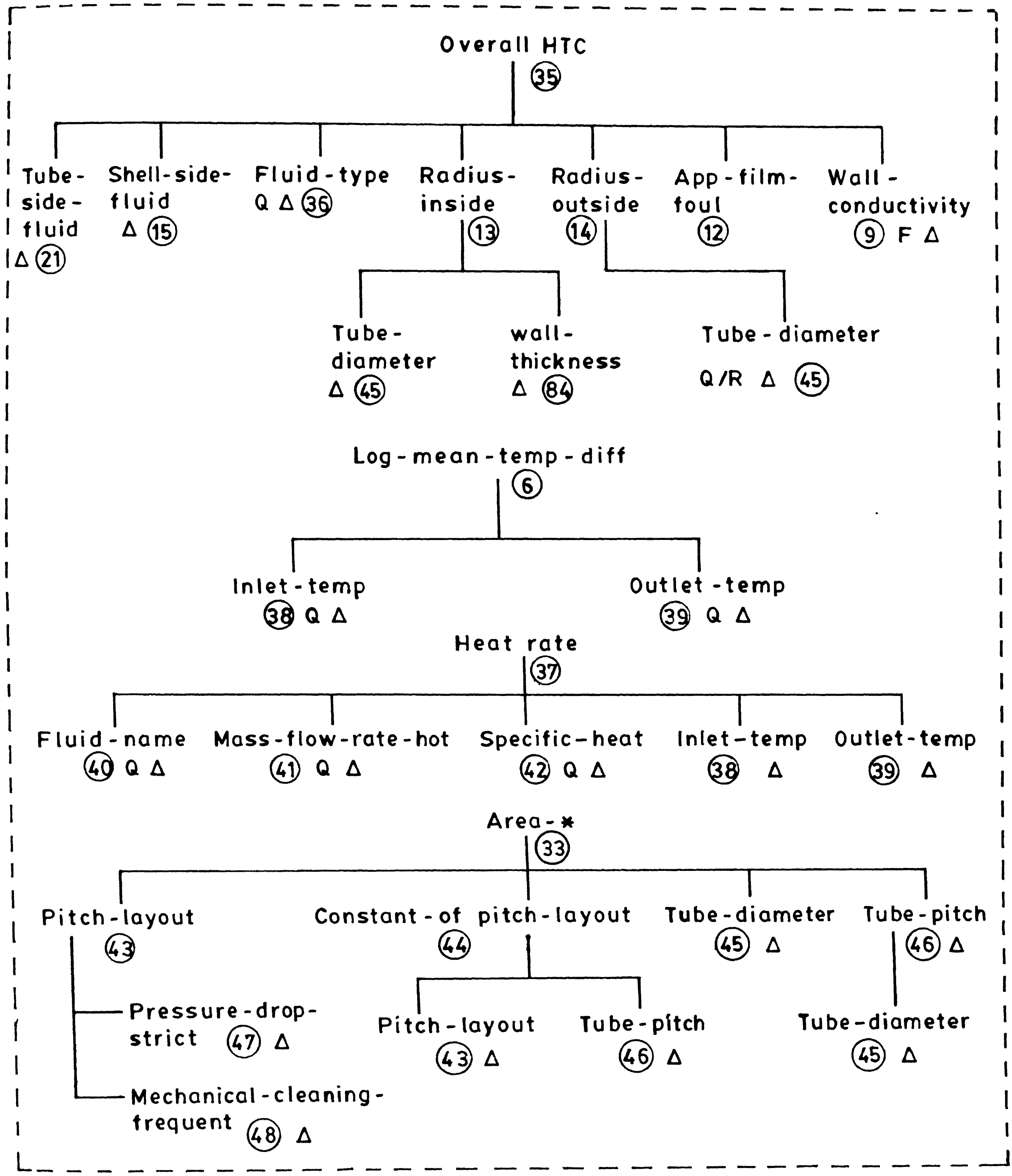

Overall HTC
35
Tube-side-fluid
Δ 21
Shell-side-fluid
Δ 15
Fluid-type
Q Δ 36
Radius-inside
13
Radius-outside
14
App-film-foul
12
Wall-conductivity
9 F Δ
Tube-diameter
Δ 45
wall-thickness
Δ 84
Tube-diameter
Q/R Δ 45
Log-mean-temp-diff
6
Inlet-temp
38 Q Δ
Outlet-temp
39 Q Δ
Heat rate
37
Fluid-name
40 Q Δ
Mass-flow-rate-hot
41 Q Δ
Specific-heat
42 Q Δ
Inlet-temp
38 Δ
Outlet-temp
39 Δ
Area-*
33
Pitch-layout
43
Constant-of pitch-layout
44
Tube-diameter
45 Δ
Tube-pitch
46 Δ
Pressure-drop-strict
47 Δ
Mechanical-cleaning-frequent
48 Δ
Pitch-layout
43 Δ
Tube-pitch
46 Δ
Tube-diameter
45 Δ

Fig. c

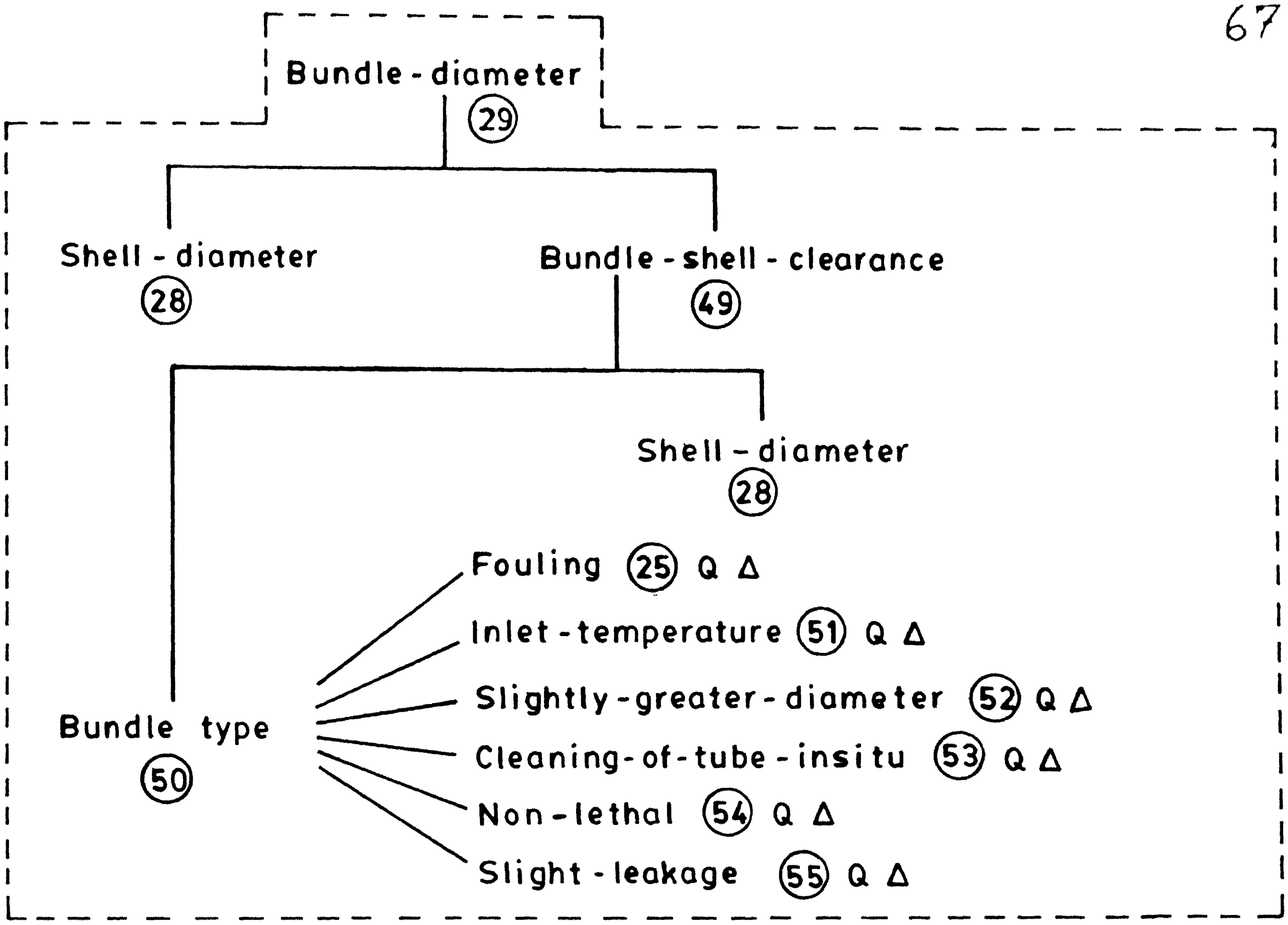

Bundle - diameter
29
Shell - diameter
28
Bundle - shell - clearance
49
Shell - diameter
28
Fouling 25 Q Δ
Inlet - temperature 51 Q Δ
Slightly - greater - diameter 52 Q Δ
Cleaning - of - tube - insitu 53 Q Δ
Non - lethal 54 Q Δ
Slight - leakage 55 Q Δ
Bundle type
50

Fig. d

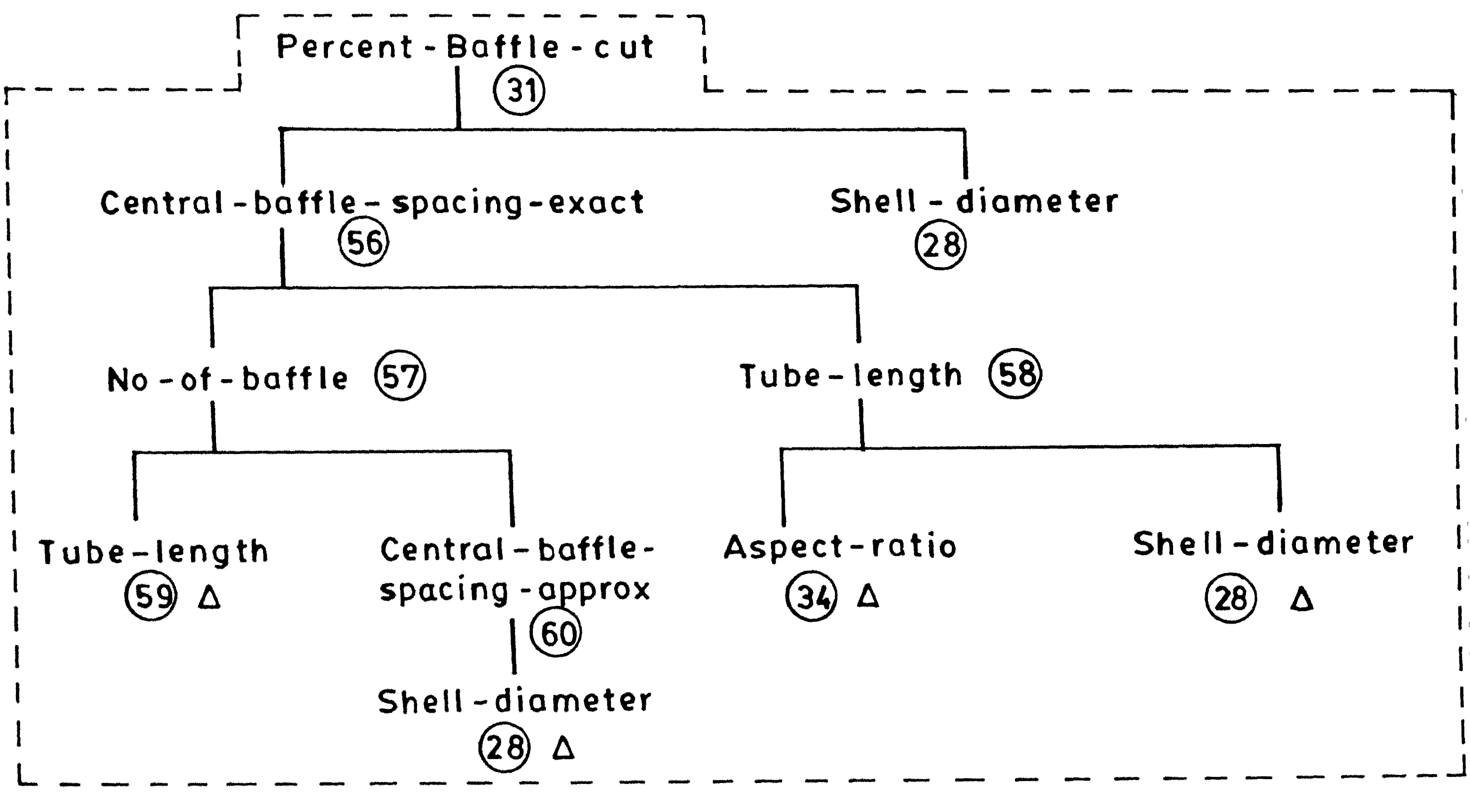
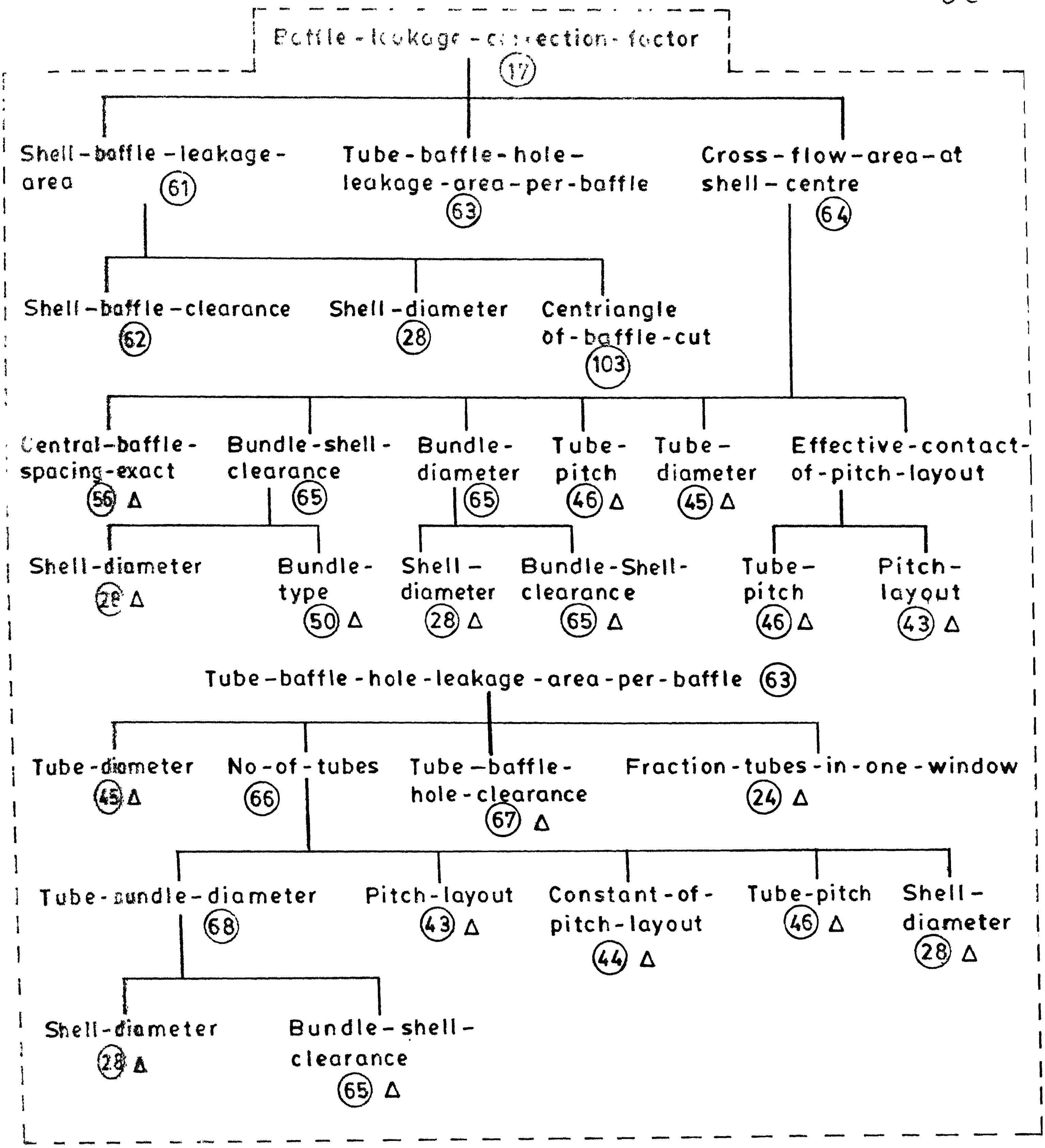

Percent - Baffle - cut
31
Central - baffle - spacing - exact
56
Shell - diameter
28
No - of - baffle 57
Tube - length 58
Tube - length
59 Δ
Central - baffle - spacing - approx
60
Shell - diameter
28 Δ
Aspect - ratio
34 Δ
Shell - diameter
28 Δ

Fig. e



Baffle-leakage-correction-factor 17
Shell-baffle-leakage-area 61
Tube-baffle-hole-leakage-area-per-baffle 63
Cross-flow-area-at shell-centre 64
Shell-baffle-clearance 62
Shell-diameter 28
Centriangle of-baffle-cut 103
Central-baffle-spacing-exact 56 Δ
Bundle-shell-clearance 65
Bundle-diameter 65
Tube-pitch 46 Δ
Tube-diameter 45 Δ
Effective-contact-of-pitch-layout
Shell-diameter 28 Δ
Bundle-type 50 Δ
Shell-diameter 28 Δ
Bundle-Shell-clearance 65 Δ
Tube-pitch 46 Δ
Pitch-layout 43 Δ
Tube-baffle-hole-leakage-area-per-baffle 63
Tube-diameter 45 Δ
No-of-tubes 66
Tube-baffle-hole-clearance 67 Δ
Fraction-tubes-in-one-window 24 Δ
Tube-bundle-diameter 68
Pitch-layout 43 Δ
Constant-of-pitch-layout 44 Δ
Tube-pitch 46 Δ
Shell-diameter 28 Δ
Shell-diameter 28 Δ
Bundle-shell-clearance 65 Δ

Fig. f

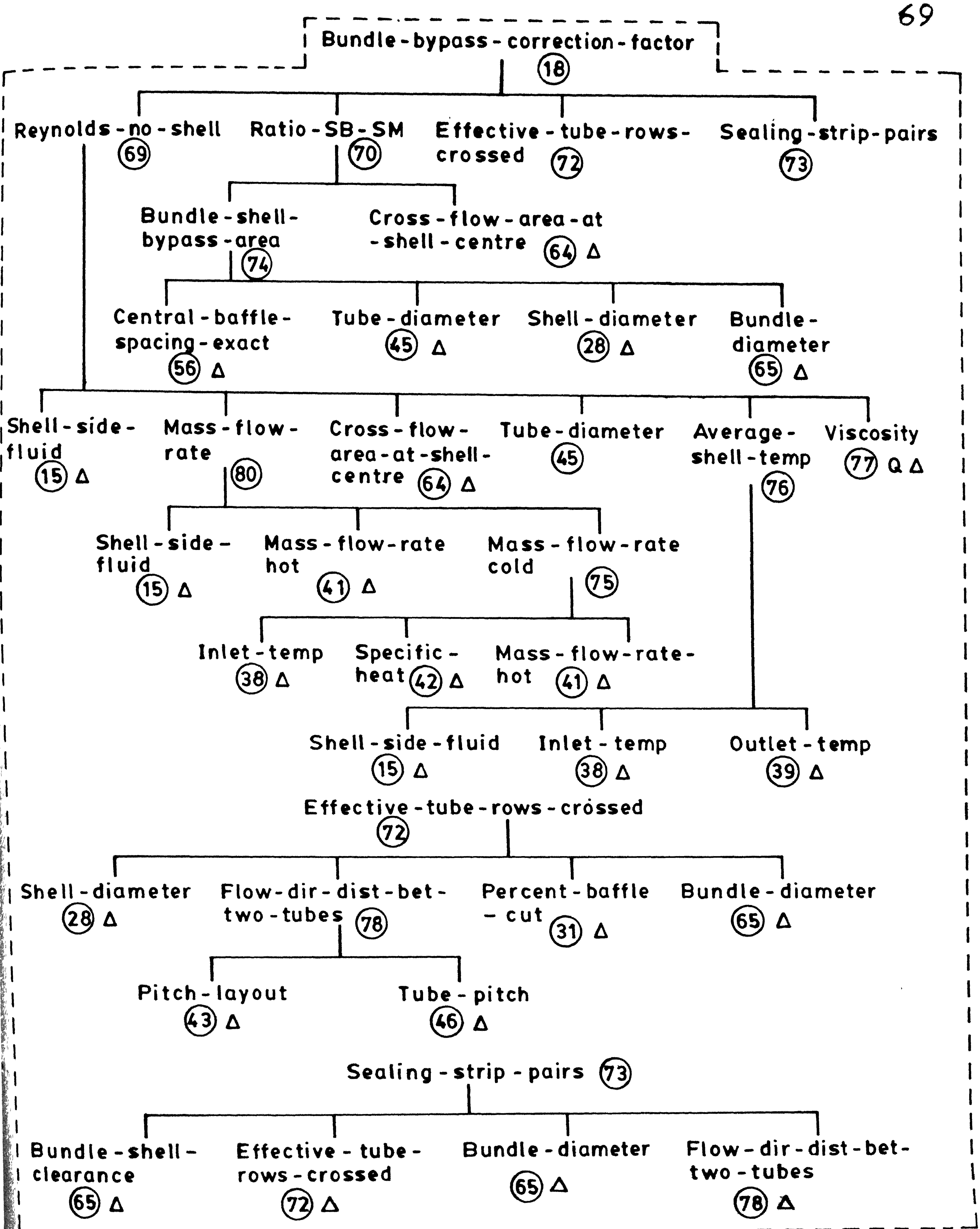

Bundle-bypass-correction-factor 18
Reynolds-no-shell 69
Ratio-SB-SM 70
Effective-tube-rows-crossed 72
Sealing-strip-pairs 73
Bundle-shell-bypass-area 74
Cross-flow-area-at-shell-centre 64 Δ
Central-baffle-spacing-exact 56 Δ
Tube-diameter 45 Δ
Shell-diameter 28 Δ
Bundle-diameter 65 Δ
Shell-side-fluid 15 Δ
Mass-flow-rate 80
Cross-flow-area-at-shell-centre 64 Δ
Tube-diameter 45
Average-shell-temp 76
Viscosity 77 Q Δ
Shell-side-fluid 15 Δ
Mass-flow-rate hot 41 Δ
Mass-flow-rate cold 75
Inlet-temp 38 Δ
Specific-heat 42 Δ
Mass-flow-rate-hot 41 Δ
Shell-side-fluid 15 Δ
Inlet-temp 38 Δ
Outlet-temp 39 Δ
Effective-tube-rows-crossed 72
Shell-diameter 28 Δ
Flow-dir-dist-bet-two-tubes 78
Percent-baffle-cut 31 Δ
Bundle-diameter 65 Δ
Pitch-layout 43 Δ
Tube-pitch 46 Δ
Sealing-strip-pairs 73
Bundle-shell-clearance 65 Δ
Effective-tube-rows-crossed 72 Δ
Bundle-diameter 65 Δ
Flow-dir-dist-bet-two-tubes 78 Δ

Fig. g

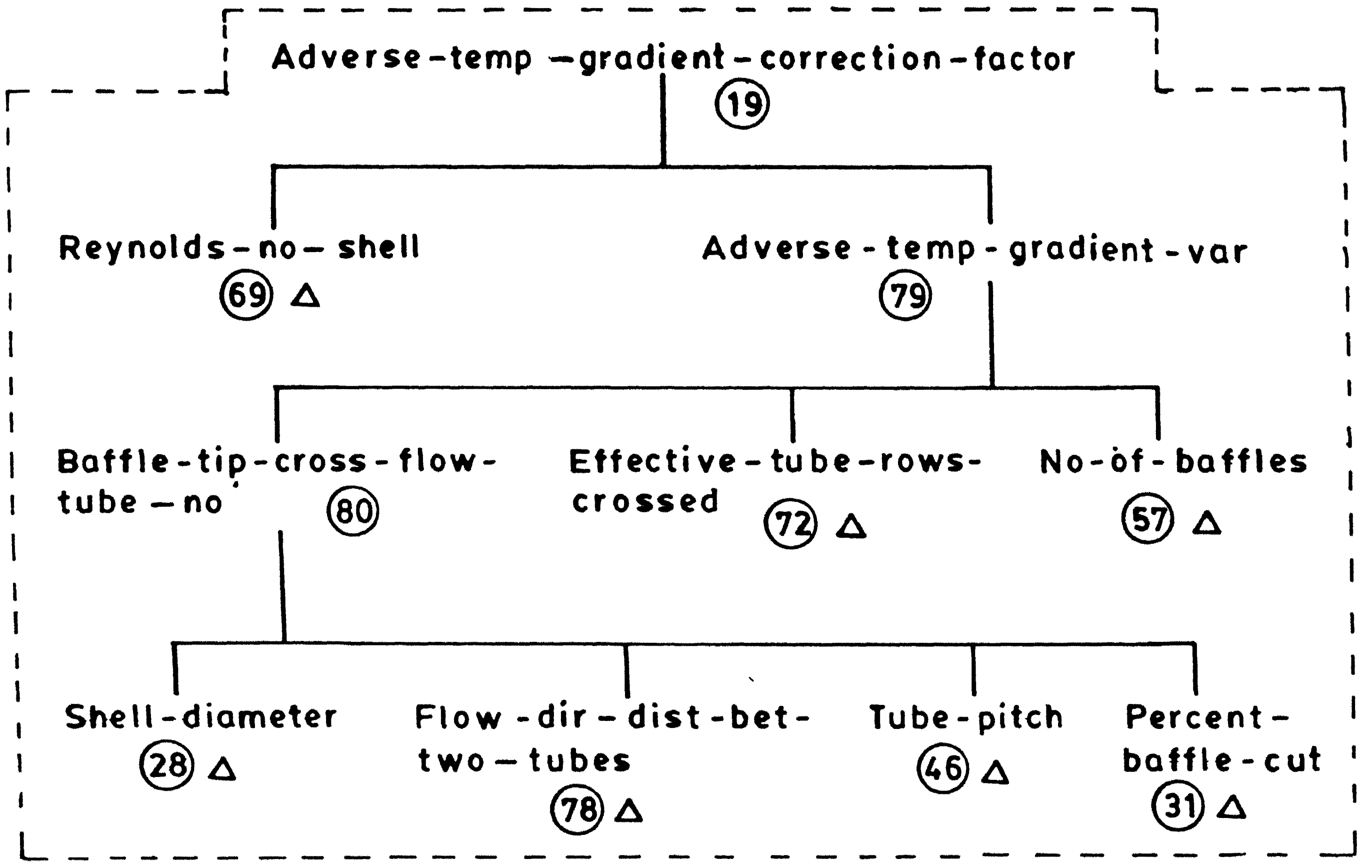

Adverse-temp-gradient-correction-factor
19
Reynolds-no-shell
69 △
Adverse-temp-gradient-var
79
Baffle-tip-cross-flow-tube-no
80
Effective-tube-rows-crossed
72 △
No-of-baffles
57 △
Shell-diameter
28 △
Flow-dir-dist-bet-two-tubes
78 △
Tube-pitch
46 △
Percent-baffle-cut
31 △

Fig. h

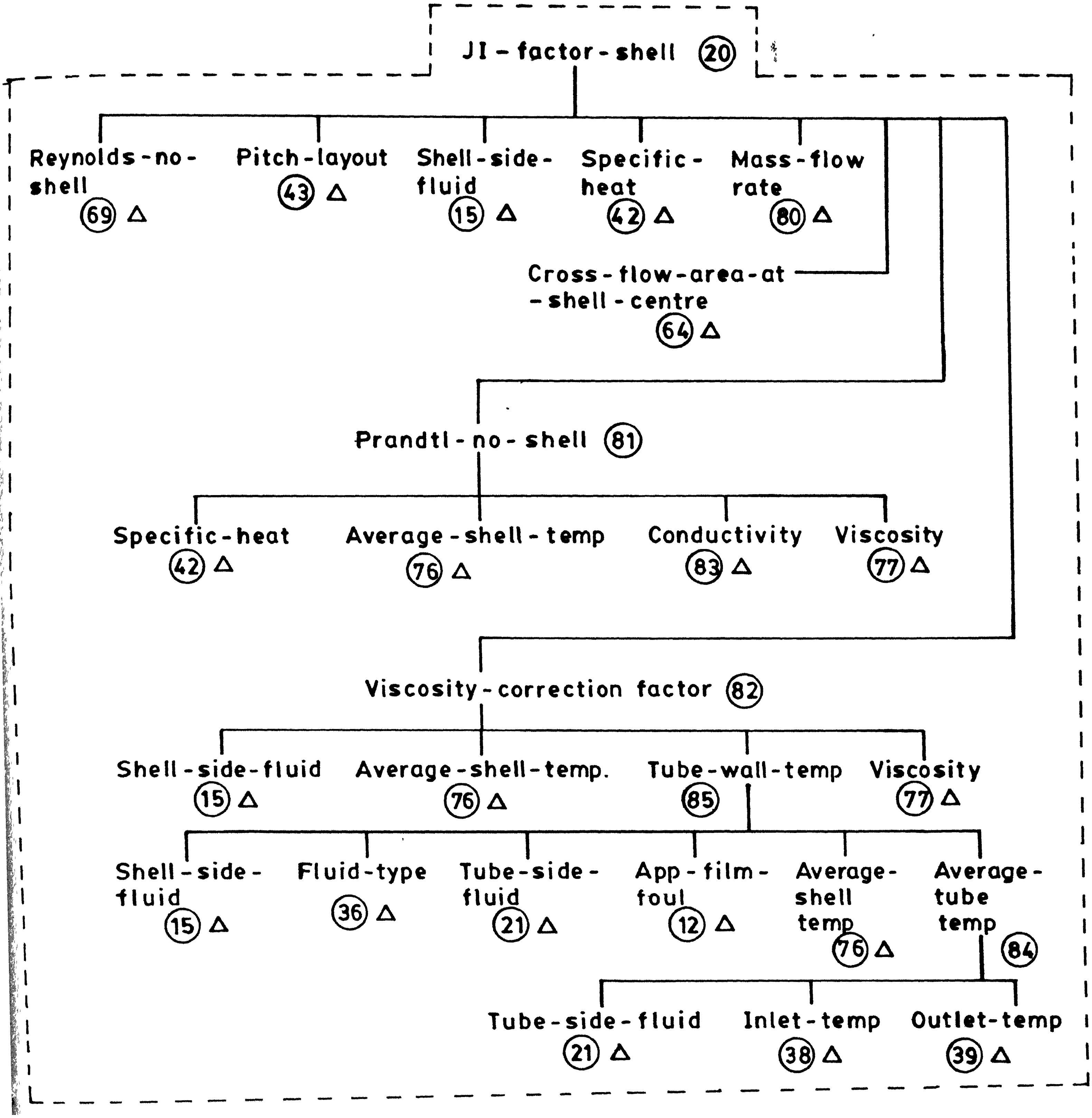

JI - factor - shell 20
Reynolds - no - shell 69 △
Pitch - layout 43 △
Shell - side - fluid 15 △
Specific - heat 42 △
Mass - flow rate 80 △
Cross - flow - area - at - shell - centre 64 △
Prandtl - no - shell 81
Specific - heat 42 △
Average - shell - temp 76 △
Conductivity 83 △
Viscosity 77 △
Viscosity - correction factor 82
Shell - side - fluid 15 △
Average - shell - temp. 76 △
Tube - wall - temp 85
Viscosity 77 △
Shell - side - fluid 15 △
Fluid - type 36 △
Tube - side - fluid 21 △
App - film - foul 12 △
Average - shell temp 76 △
Average - tube temp 84
Tube - side - fluid 21 △
Inlet - temp 38 △
Outlet - temp 39 △

Fig. i

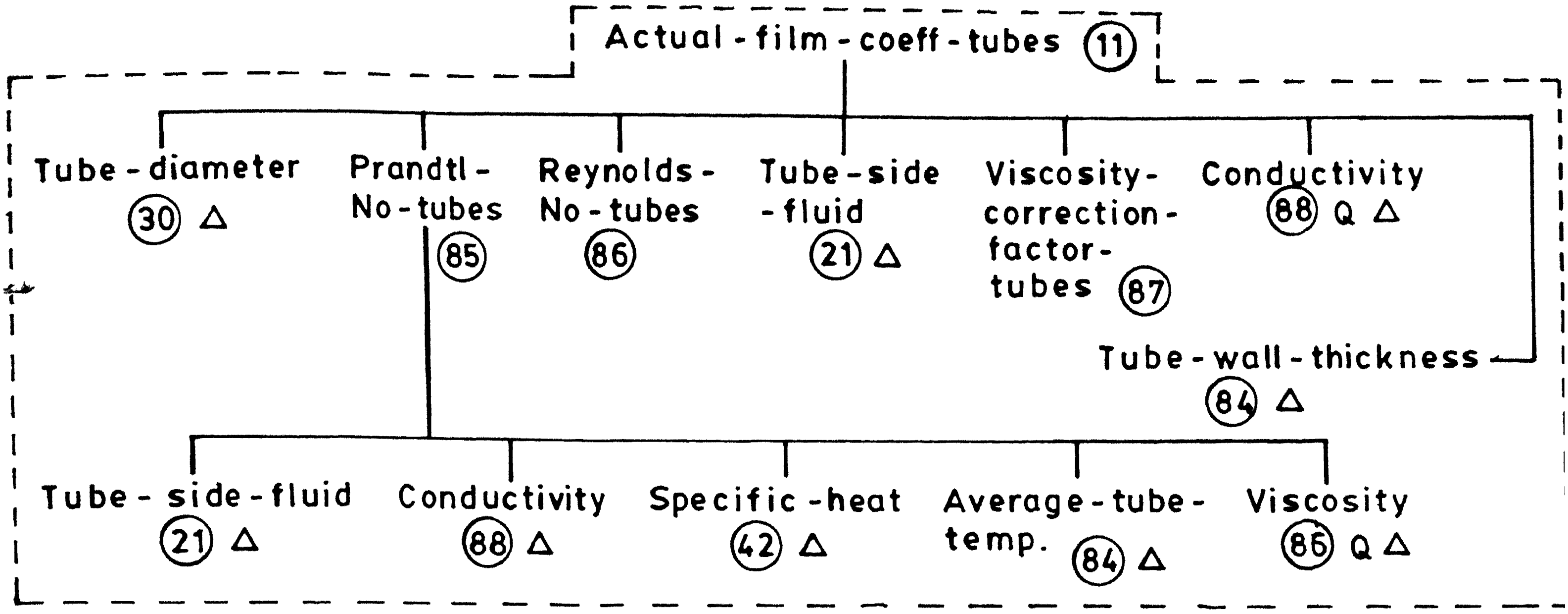

Actual - film - coeff - tubes 11
Tube - diameter 30 △
Prandtl - No - tubes 85
Reynolds - No - tubes 86
Tube - side - fluid 21 △
Viscosity - correction - factor - tubes 87
Conductivity 88 Q △
Tube - wall - thickness 84 △
Tube - side - fluid 21 △
Conductivity 88 △
Specific - heat 42 △
Average - tube - temp. 84 △
Viscosity 86 Q △

Fig. j

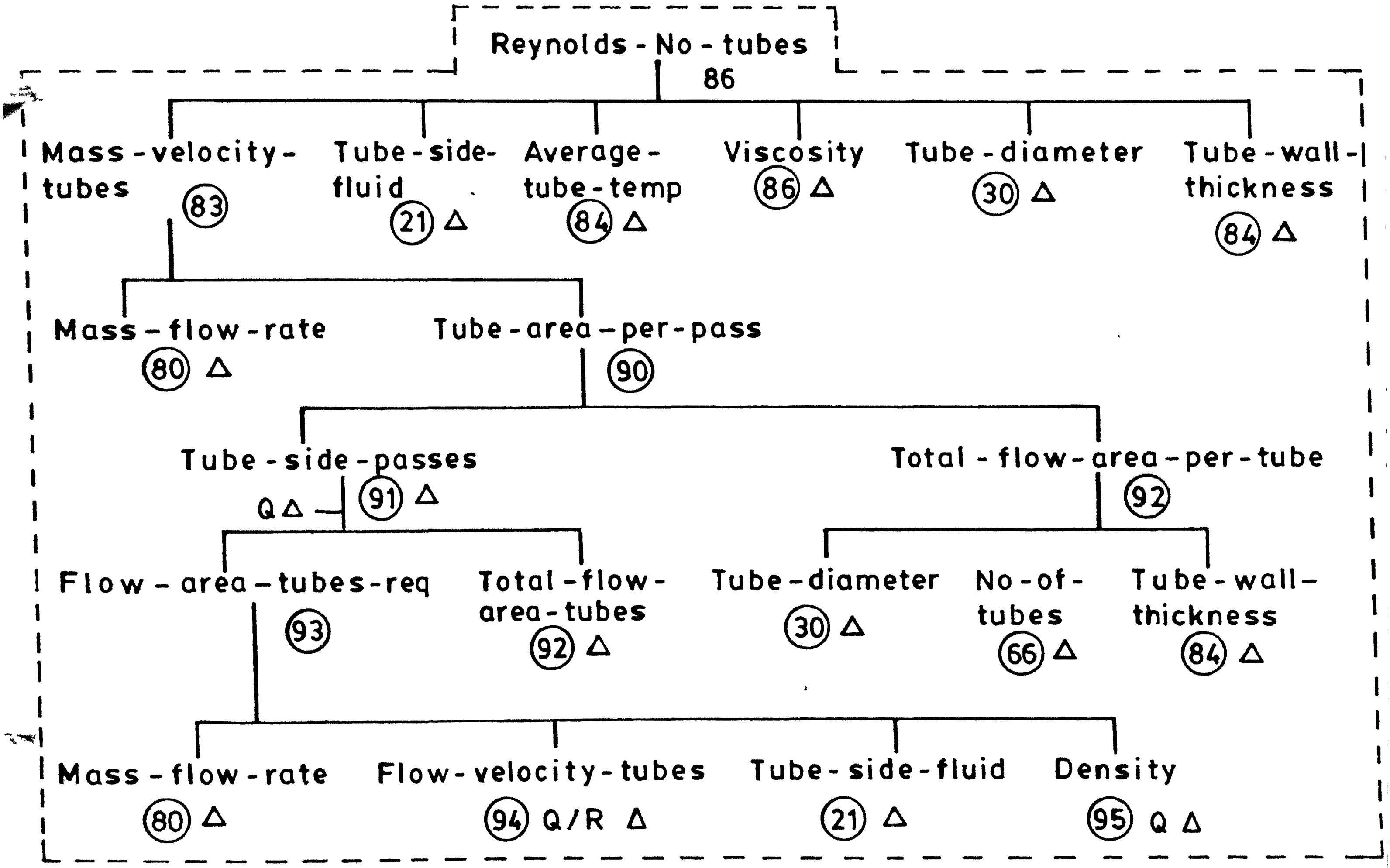

Reynolds - No - tubes 86
Mass - velocity - tubes 83
Tube - side - fluid 21 △
Average - tube - temp 84 △
Viscosity 86 △
Tube - diameter 30 △
Tube - wall - thickness 84 △
Mass - flow - rate 80 △
Tube - area - per - pass 90
Tube - side - passes 91 △
Q △
Total - flow - area - per - tube 92
Flow - area - tubes - req 93
Total - flow - area - tubes 92 △
Tube - diameter 30 △
No - of - tubes 66 △
Tube - wall - thickness 84 △
Mass - flow - rate 80 △
Flow - velocity - tubes 94 Q/R △
Tube - side - fluid 21 △
Density 95 Q △

Fig. k

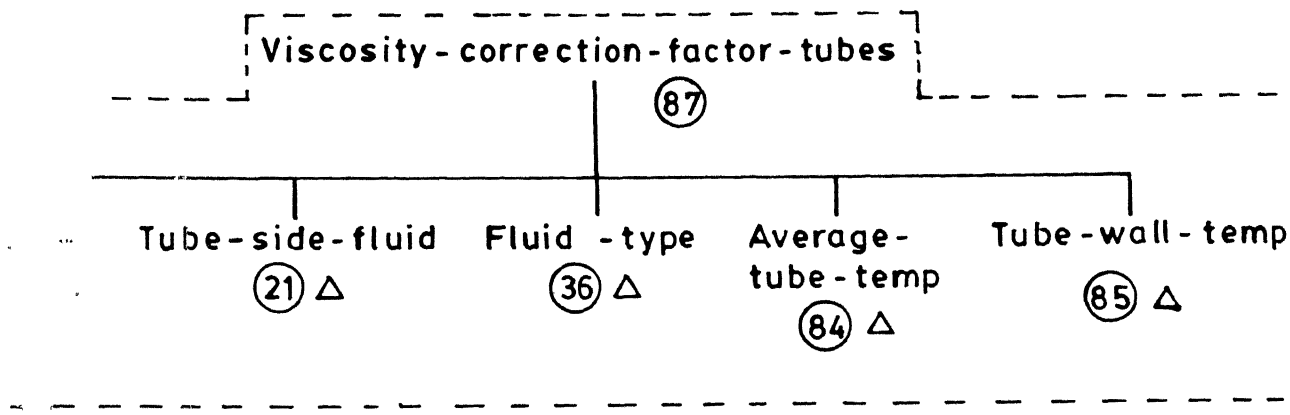

Viscosity-correction-factor-tubes
87
Tube-side-fluid
21
Fluid -type
36
Average-tube-temp
84
Tube-wall-temp
85

Fig. l

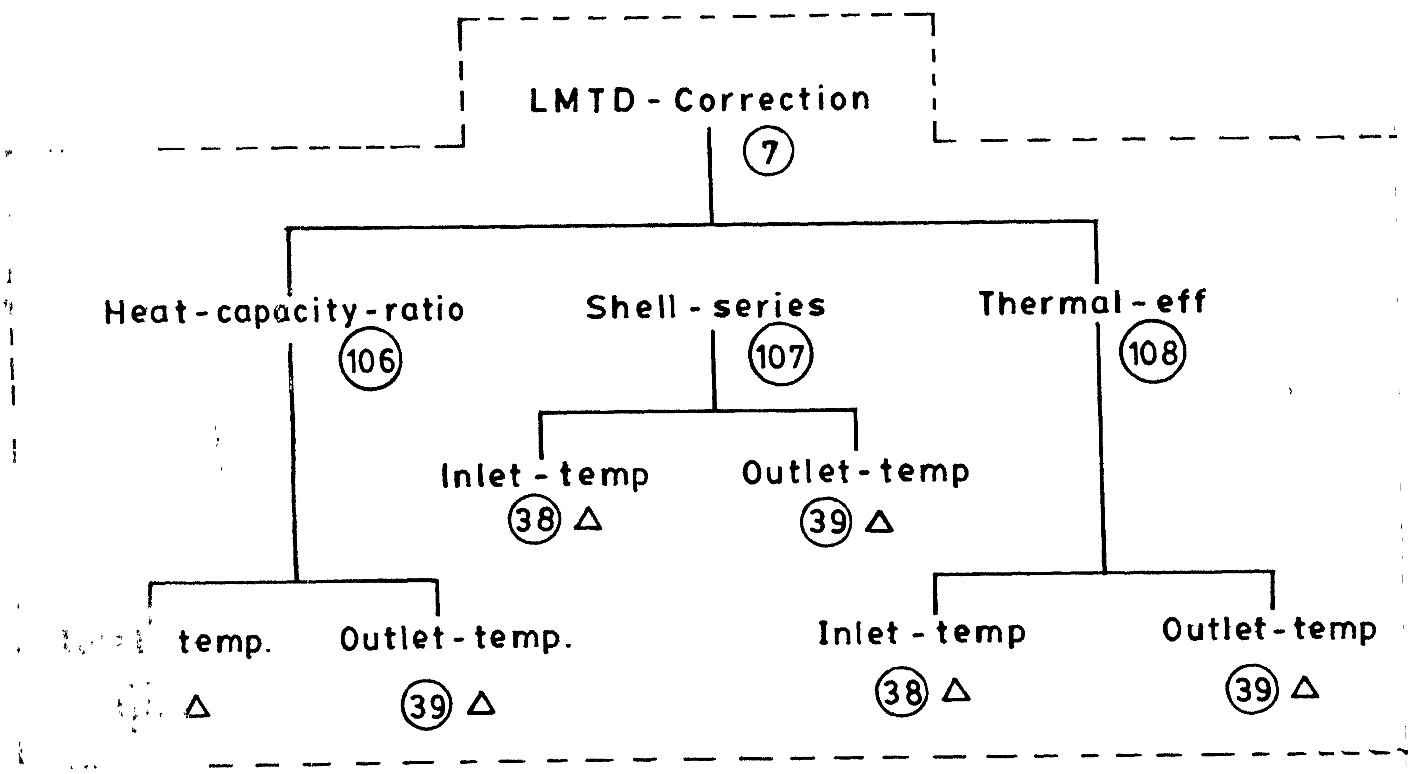

LMTD-Correction
7
Heat-capacity-ratio
106
Shell-series
107
Thermal-eff
108
Inlet-temp
38
Outlet-temp
39
temp.
Outlet-temp.
39
Inlet-temp
38
Outlet-temp
39

Fig. m

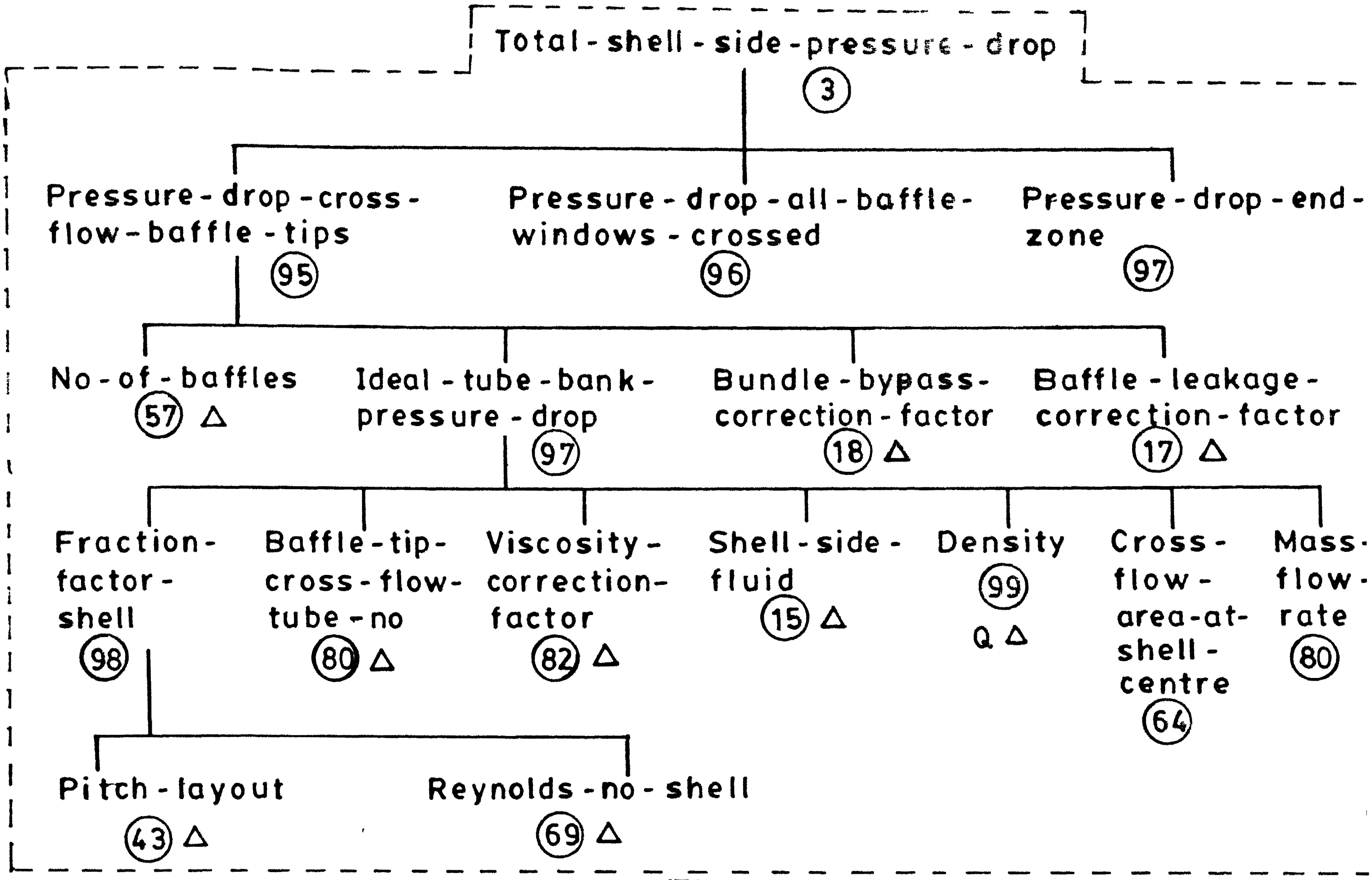

Total-shell-side-pressure-drop
3
Pressure-drop-cross-flow-baffle-tips
95
Pressure-drop-all-baffle-windows-crossed
96
Pressure-drop-end-zone
97
No-of-baffles
57 △
Ideal-tube-bank-pressure-drop
97
Bundle-bypass-correction-factor
18 △
Baffle-leakage-correction-factor
17 △
Fraction-factor-shell
98
Baffle-tip-cross-flow-tube-no
80 △
Viscosity-correction-factor
82 △
Shell-side-fluid
15 △
Density
99
Q △
Cross-flow-area-at-shell-centre
64
Mass-flow-rate
80
Pitch-layout
43 △
Reynolds-no-shell
69 △

Fig. n

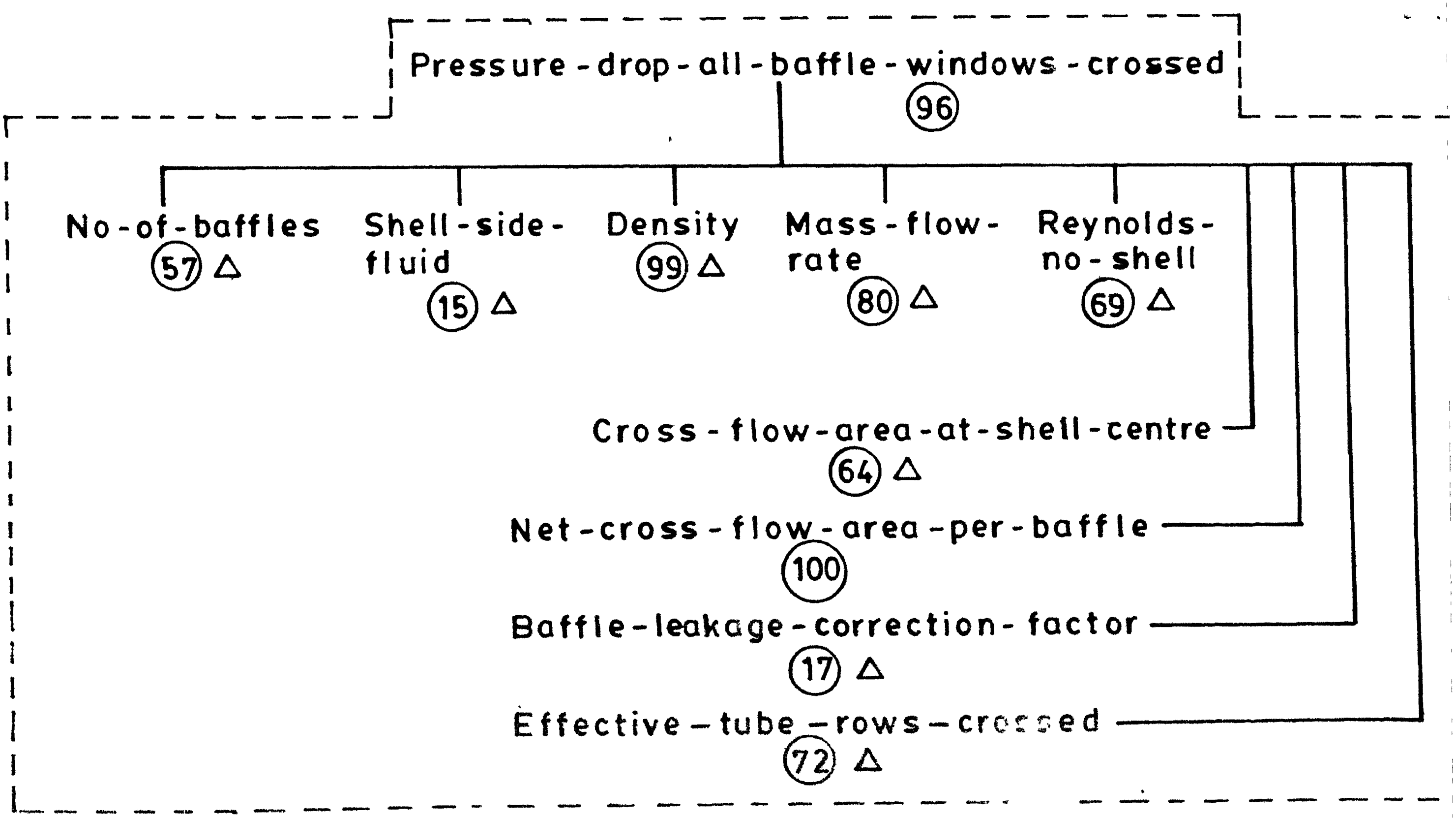

Pressure-drop-all-baffle-windows-crossed
96
No-of-baffles
57 △
Shell-side-fluid
15 △
Density
99 △
Mass-flow-rate
80 △
Reynolds-no-shell
69 △
Cross-flow-area-at-shell-centre
64 △
Net-cross-flow-area-per-baffle
100
Baffle-leakage-correction-factor
17 △
Effective-tube-rows-crossed
72 △

Fig. o

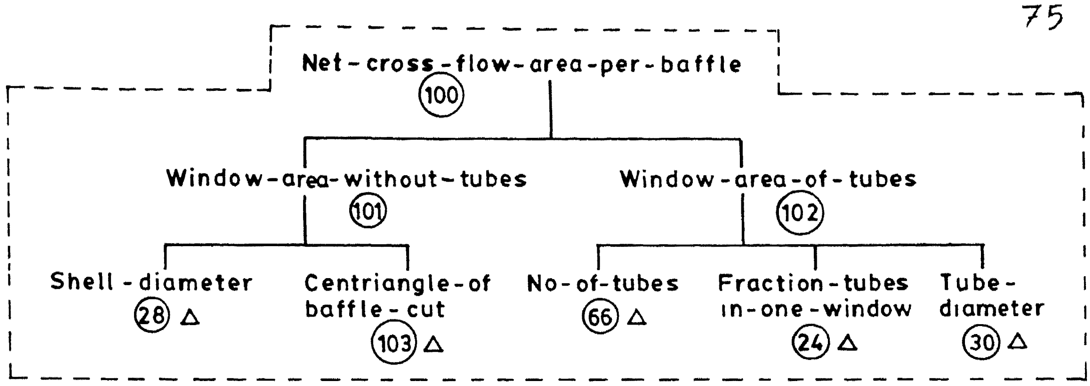


Fig. p

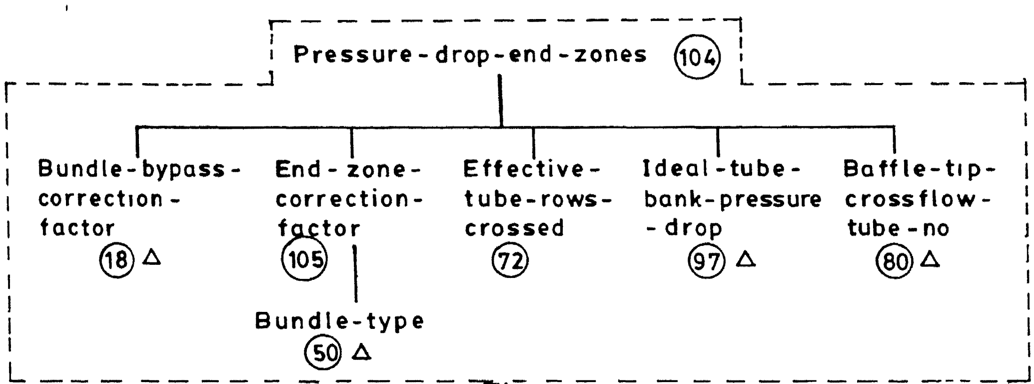


Fig. q

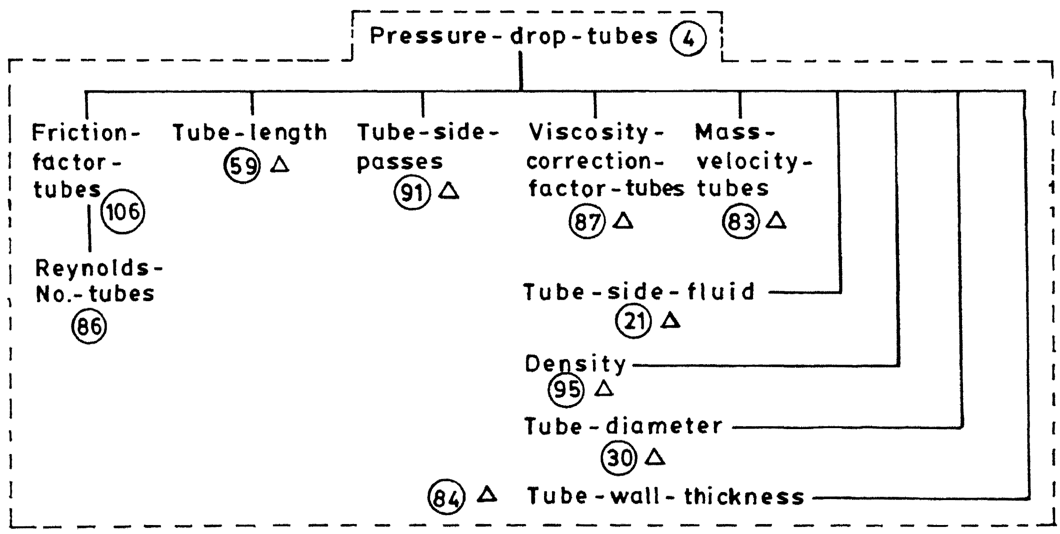


Fig. r

4.2 GENERATING THE QUERY TREE :

The query tree generated is shown in Fig. 4.2. Each block represents a sub query tree, details of which are shown in **Fig.** 4.4 . The blocks shown in Fig. 4.3 and 4.4 are same except for the fact that Fig. 4.4 shows a detailed tree structure.

It may be pointed out that the flow chart for the design will be the same but the tree structure depends totally on the structuring of the rules and the users responses. Hence it is a dynamic structure and may vary from session to session. In the present system, the queries are to be satisfied from the left to right.

We will examine in detail a query tree for determining the bundle diameter. Bundle diameter is calculated as the difference between shell diameter and the bundle-shell clearance. The bundle shell clearence is a function of shell-diameter and the bundle type. Bundle type depends upon the fluid properties like fouling, Inlet-pressure, non-lethal characteristics and mechanical cleaning frequency. Hence it can be seen that the query (Bundle-Diameter ?X) generates question like fouling characteristics, slightly greater diameter, non-lethal characteristics and slight leakage.

In similar manner each of the block can be analysed to its detailed tree as shown in Fig. 4.3. The

symbol ⌂ denotes that the query for that particular predicate is satisfied at that stage or any stage previous to that.

4.3 STRUCTURING OF THE RULES:

As explained in Chapter 2, this system is a backward driven system. When a goal is given, the system tries to satisfy that goal, by scanning through the facts, rules, etc.

A detailed rule heirarchy structure is shown in Fig.4.4.

The top level predicate is 'complete'. To satisfy this goal, 3 subgoals should be satisfied viz. Area-req, Total-shell-side-spressure-drop and tube-side pressure drop. Area-req further requires 4 goals and so on. The order of goals to be satisfied is from left to right i.e. the left goal is to be satisfied first then the next one and so on.

It is observed that some of the goals are required to be satisfied at many places. The context is declared to be true for all the predicates except computational predicates. This means that all the inference is stored as a fact and when it is required next time in the subsequent rules, it is directly inferred from the fact itself thus saving the laborious task of applying the rule again and again.

This feature of storing the inference poses one problem. When a predicate is inferred, at some stage we may want the value of this predicate arguments to be changed. Such a thing is possible by defining it as an action predicate or defining a predicate with another name. The process of reseting the database is adopted here.

The predicates whose value of the argument needs to be changed are identified and listed. The order of operation for these predicates is changed as-

1. Compute-pred
2. Action-pred
3. Facts
4. Question
5. Rules
6. Question-proc.

This differs from the regular order of operation as mentioned in Section 2 in the sense that the question is asked before the rule.

So initially, when an approximate value is to be determined, the user has to say 'DONTKNOW' so that the rule which computes the value is applied.

After the preliminary round of rating is over, in the next round the properties are ' Reset' to the orignal i.e. they lose all the newly generated facts and the system is

again ready to apply the same rules. This feature of asking the question is also useful when the user knows some piece of information and wishes to override the procedure that exists for computing that value. For e.g. if he already knows the tube-side heat transfer coefficient, he can give the value and override the usual procedure of computing the tube-side heat transfer coefficient

4.4 DIFFERENT PREDICATES USED:

The computational predicates take their arguments and return True (T) or false (Nil) according to the condition e.g. <,>, =, LE,GE etc. (LE = less than or equal to and GE = Greater than or equal to.). Most of the predicates defined for this system take one argument which is a numerical value e.g. Heat-rate, no-of-tubes, shell-diameter. Such predicates essentially have a rule, and most of the time they are enferred from a rule. They can get their value from the question also as explained in the previous section.

Other types of predicates are those which have more than one argument. The need for defining such predicates arises because of change in references and requirement of storing many properties. In the initial stage when the shell side and tube-side fluids are not decided, questions are asked by referring to the fluids as hot fluids and cold-fluids. All the inference till this stage is made by referring the streams as hot and cold. Once the fluids on shell

and tube side are determined, they are referred by the predicates shell-side-fluid and tube-side fluid so (Inlet-temp. ?name ? T-I) is a predicate having name of the fluid as its first argument and the value as its second argument. The first argument can be had from either of the two predicates as explained -

```
(fluid-name  hot-fluid   ? name)  or
(shell-side-fluid        ? name)
```

Another example is

```
(App-film-foul   ?type  ? HTC  ?Fouling-coeff)
```

This predicate stores the values of Heat-transfer coefficient and Fouling coefficients for different types of fluids.

4.5 KINDS OF RULES:

The rules used here are mostly of the type which use an expression for assigning value to a variable argument of the predicate .

A rule of the form

```
((( Area-req   ? A-req)
 (( Overall-HTC-actual ? U-O)
  ( LMTD - correction  ? F)
  ( Heat-Rate          ? Q-O)
  (=  ?A-Req (* Quo  ?Q-O  (* ? U-O  ?LMTD  ?F)))
ST 133))
```

is equivalent to the expression

$$A_{req} = \frac{Q_o}{U_o (LMTD) F}$$

This can be asserted as a logic expression as (Area-req ?X) ⟵ (overall-HTC-actual ? U-O),

```
(Heat-rate ?Q-O), (LMTD-Correction ?F),
( = ?X (*Quo ?Q-O (* ?U-O ? LMTD ? F))),
```

The second type of rule is one which takes purely logical decisions. Consider the rule

```
((( Shell-side-fluid ? name -C)
 (( Fluid-name    cold-fluid   ? name-c)
  (Fluid-name   hot-fluid  ?name -h)
  (Tube-side-fluid  ? name - h)
ST 3))
```

here this rule cannot be expressed as a mathematical statement, but it takes a logical decision that if it can be proved that there is hot-fluid on the Tube-side, then it can be inferred that the other (cold-fluid) is on the shell-side.

4.6 ENCODING A NEW RULE:

Here we will talk about creating new predicates and writing a rule. Consider the following statements

' The decision of tube-side, shell-side or direct condensation depends upon the following:

1. High pressures are best inside tubes
2. Shell side has a relatively low pressure drop.
3. Corrosive vapours should be on the tube side.
4. If the operating temperature is very high, use direct-condensation.

5. If the condensate can freze during the heat transfer process, shell side condensation is preferred.
6. When condensing multicomponent mixtures having a substantial boiling or dew-point range, or when there are soluble gases present, it is necessary to control the condensate and vapour flow so as to enable the low boilers to condense or when stripping to prevent their condensation or absorption, use tube side-condensation.
7. Fouling vapours should be best placed on the tube side.
8. Venting:'If non-condensables are to be vented, use tube side condensation'

The first step is to arrange these statements in order of importance. This is the first and the most important step towards writing the rules.

Along with this, select the important parameters and call them as predicates. So we have-

Order of importance	Serial number	Predicates
1	3	(corrosive <name> < yes/no>)
2	5	(freezing <name> <yes/no>)
3	6	(multi-component-vapours<yes/no>)
		or (soluble-gas-present <yes/no>)
		and(control-condensate-vapour flow <yes/no>)

Order of importance	Serial number	Predicates
4	1	(inlet-pressure ? name ? P-I)
		(< ?P-I 2000.0)
5	4	(inlet-temp ? name ? I-I)
		(> ?T-I 300.00)
6	8	(venting-noncondensables <yes/no>)
7	2	(Pressure-drop-max-low <yes/no>)
8	7	(fouling <name> < yes/no>)

now using the syntax, rules can be written. One can have predicate of the type-

(Condensation tubeside) or

(Tube-side-condensation) The latter one is used here

```
(Defprop   Tube-side-condensation
(((Tube-side-condensation)
 ((Fluid-name   hot fluid    ?name -h )
  (Corrosive   ? name-h   ?X )
  ( =    ? X    YES))
 No 1 ))
 Rules)
```

CHAPTER 5

RESULTS AND DISCUSSION

5.1 USING THE PACKAGE:

The various steps are explained in sect.3.1. The user is expected to identify the problem and select a STHE as a solution. This system does all the steps in the .... block shown in Fig.5.1. While using this system, the user is expected to answer questions. The data are supplied essentially by question and answer process.

Questions asked can be classified into 2 categories.

1. Mandatory questions and
2. Optional questions

1. Mandatory Questions:

The user may have a requirement of heat exchange between any two fluids. Since the fluids undergoing heat exchange are best known to the user and so also are the properties, the user should supply them to the system when they are asked. For mandatory questions, if the user types 'don't know' there is no way the system can get this value and hence the attempt fails. For example a typical mandatory question is 'give the inlet temperature of hot fluid in degrees celsius'. All the mandatory questions are self

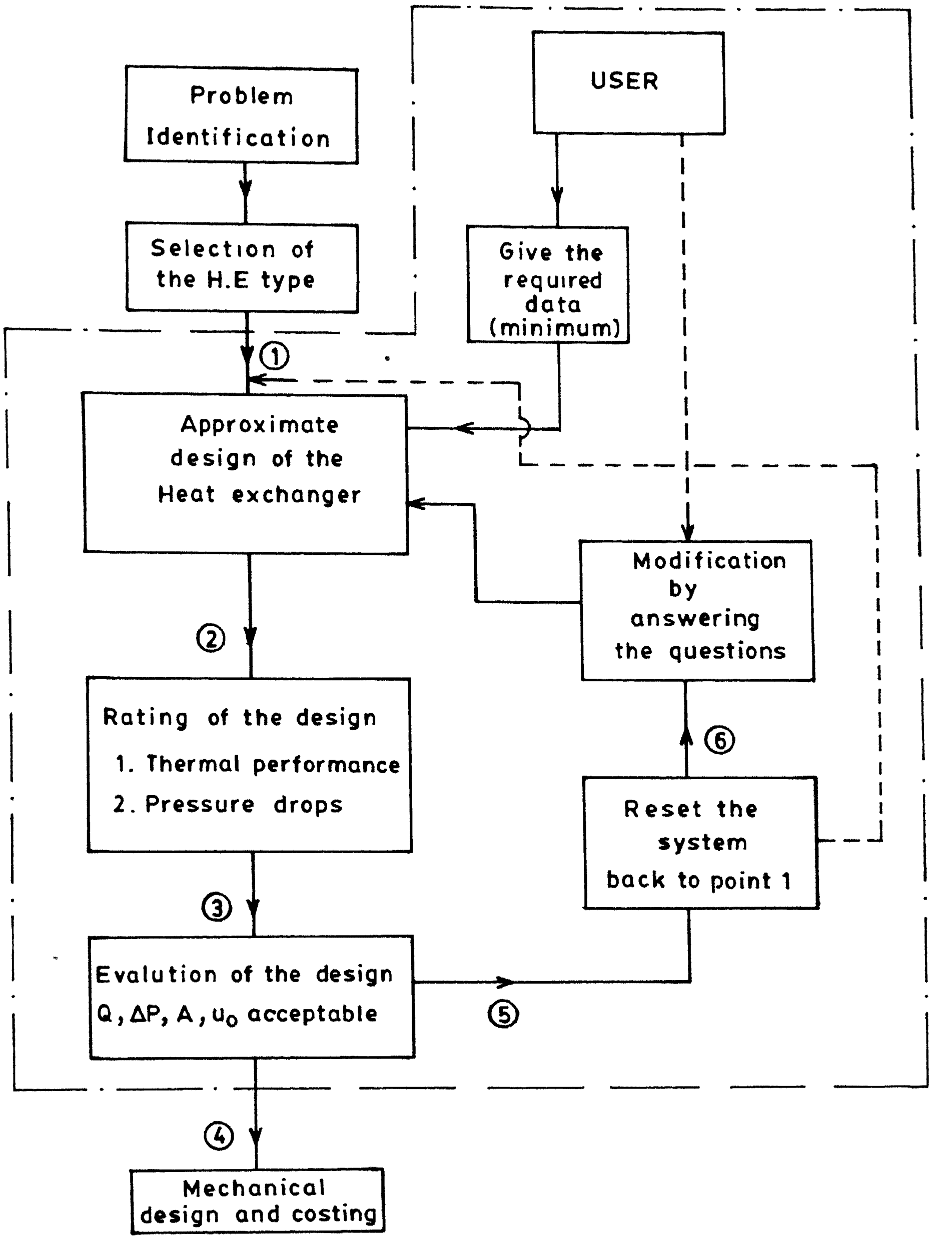


Fig. 5.1 Methodology for using the system.

explanatory, and they demand certain values. There is no information stored for them (See Table 5.1).

2. Optional Questions:

Some questions help as guide lines in selecting the bundle type, fluid side etc. If all the questions are not successful, there is still some decision taken, but it becomes a conservative or extra safe, decision. Answering the optional questions helps in getting the HE design precisely to the user needs, and so user should attempt to answer these questions, These questions are interdependent i.e. a question may be asked only if the user fails to answer the previous question :

Thedatabase for the Rule based system for heat exchangers is stored in 2 files.

FIXED AND ITER

FIXED essentially consists of the parameters which will not be changed in the process of redesigning, They are essentially the fluid properties and characteristics. ITER contains the bulk of the Rule base and is the one that rates the heat exchanger. The system consists of 148 Rules, 35 questions and explanations. The user is expected to fill up the tables I and II to facilate the use of this system. Table I contains the essential questions which he should know and table II contains some questions which may be required to be answered .

The complete design of a heat exchanger is an iterative process and can be best handled by the user himself.

A. After loading the files FIXED and ITER the user can start the system by typing Design. Before answering any question, he should read the instructions for answering the question carefully. If the user does not know the answer for the question, he should first get the explanation by typing 'What' and see what are the alternatives he has got.

At the end, a short comparative table is printed which gives the values required for comparison.

This table is shown in the sample run . The user should examine the output and decide whether or not the design is acceptable. The following should be taken into consideration.

1. Area required for heat transfer should in no case be greater than the area available for heat transfer.

2. Area required may be smaller than the area available, but this descision can be made by the user himself. Larger difference is advantageous from reliability point of view, but is not economical.

3. The required area and available area may be acceptable, but not the pressure drop on the shell and tube sides. The initial design may have the lowest pressure drop which will result in a very expensive design of the HE.

The user should compare the actual pressure drop and the permissible pressure drop. A rough guide for determining the maximum permissible pressure drop is given below, (Lord, 1970).

Inlet pressure kPa	Maximum permissible pressure drop kPa
Sub atmospheric	1/10th of absolute pressure
6.8 kPa to 68.9 kPa (gauge)	1/2 of operating gauge pressure.
68.9 kPa and higher	34.5 kPa or higher

A good design is the one which utilizes the maximum permissible pressure drop, and has the highest heat transfer coefficient.

It may be noted at this point that the pressure drop, Reynolds nnmber and Heat transfer area are mutually interdepent. Heat transfer coefficient can be encreased by increasing the Reynolds number, but this increase in Reynolds number increases the pressure drop also.

It is therefore, not possible to predict the exact behaviour of the heat transfer coefficient, pressure drop, and Area of heat transfer required simultaneously. A trial and error solution is the only way.

4. Baffle leakage correction Factor for Heat Transfer (J_1):

A good design should have its value not less than 0.6. It can be increased by increasing the cross flow area at shell centre or by decreasing the number of baffles. The initial design has the maximum value J_1 can attain and hence

while iterating, case should be taken to see that it does not fall below 0.6.

5. Total Correction Factor:

The product of the all 3 correction factors should be $\geq$ 0.5 for a well designed H.E. and should never be < 0.4.

B. Iteration:

When the user is not satisfied, the system automatically iterates. The user should not down the values from the comparison table and take the decisions as explained in the previous section. He should write down what changes he wishes to make under to corresponding columns (see Table 5.3). The user can also save the previous session.

During iteration only slected questions are asked and the user should answer them if he wishes to change the values.

Many question are interdependent and the user should answer those questions only e.g. The tube side passes and flow velocity intubes. Flow velocity inside the tubes in required to determine the tube side passes, but if the user can manipulate the number of tubeside passes himself, the question regarding tubeside velocity will not be asked.

After this short session of questions, the same table of results will be displayed for the user to take his decision.

TABLE 5.1

MANDATORY QUESTIONS

Question		Hot fluid	Cold fluid
Name of the fluid			
Specific heat	J/Kg K	value	value
Inlet temperature	^{o}C	value	value
Outlet temperature	^{o}C	value	value
Mass flow rate	Kg/Sec.	value	-
(Liquids only) absolute viscosity at average temperature	cp	value	value
(Liquids only) absolute viscosity at some other temperature	cp	value	value
Density	Kg/m^3	value	value

TABLE 5.2

ITERATIVE PROCEDURE

Sl. No.	Parameter	Units	Itration no 1	2	3	4
1.	Heat transfer area required	m^2				
2.	Actual Heat Transfer area available	m^2				
3.	Shell side Re					
4.	Tube side Re					
5.	Shell side fluid					
6.	Tube side fluid					
7.	Film coefficient tube side	W/m^2K				
8.	Film coefficient shell side	W/m^2K				
9.	No of Baffles					
10.	No of Tubes					
11.	Overall Heat Transfer Coefficient	W/m^2K				
12.	Total shell side pressure drop	kPa				
13.	Total Tube side pressure drop	kPa				
14.	No of shell side pases	kPa				

It is observed that the solution is obtained faster if the actual heat transfer coefficient value from the previous round is supplied, instead of supplying the area of heat transfer.

After it is decided that there will not be any changes in the design, the final output is printed.

Results are listed in the form of a table and are devided in 3 sections. They are presented at the end of Chapter 5.

5.2 SAMPLE SESSIONS:

Three sample sessions are presented here to illustrate how the expert system will respond if the required questions are not answered or answered in a typical manner (see Appendix)

Sample sessions I and II refer only to the mandatory question. If these questions are not answered, the system just fails. If these questions are answered in a different manner, it may result in an entirely different arrangement of the heat exchanger. For example if the user has been asked, 'Is the hot gas significantly corrosive?' and the answer given is 'YES', this fluid will be placed on the tube side and the other fluid on the shell side. If the answer was 'NO', other factors will decide which fluid will be on the tube side and which one on the shell side.

Sample session III gives an idea of a normal session to the reader. It starts with the system asking questions. The

user responds to the questions by seeking various explanations, etc. The session shows iteration for 3 times. In each case the users objective was to match the actual heat transfer area required and the area available for heat transfer. It can be noted that the user has to answer very few questions while iterating since all the other properties are stored as facts. The user has the facility of storing and recording the session.

5.3 CONCLUSIONS:

An 'Expert System' based upon the logic programming for the thermal design of single phase flow STHE has been developed. The system is highly interactive which gathers information about the problem domain by asking the user relevant questions and giving him the necessary help and explanation(s) if required. The system can be used pretty easily by a commercial user for design purposes. It can also be used for learning heat exchanger design or teaching the same to a beginner.

The detailed design procedure for STHE which consists of the shell and tube side designs, has been studied. Of all the (design) procedures available for the shell side analysis, modified Bell-Delaware method has been used. As the flow in the actual STHE is a non-ideal cross flow, the relevant correction factors which can take this deviation into consideration have been calculated. Kern's method has been used for the tube side analysis.

The complete design procedure of STHE has been transformed into a knowledge base comprising of rules , facts, questions and explanations, which gives rise to a query tree indicating the flow of control.

The expert system presented here can be modified to be able to add a new rule, change any of the value already given and obtain information about various parameters at the intermediate stage. It can be extended to incorporate the rules for the design of other types of heat exchangers.

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        APPENDIX , SAMPLE SESSION I

****************************************************************

RECORD FILE DSK: SES1 OPENED 04-AUG-86 10:13:41
(GIVE THE VALUE OF FILM COEFFICIENT OF THE SHELL-SIDE-FLUID IN W / SQ M K) >DONTKNOW

(GIVE THE AREA OF HEAT TRANSFER IN SQ M) >DONTKNOW

(GIVE THE VALUE OF OVERALL HEAT TRANSFER COEFFICIENT IN W / SQ M K) >DONTKNOW

(WHAT IS THE NAME OF THE HOT-FLUID) >WHAT

(THIS IS A MANDATORY QUESTION)
>DONTKNOW

(WHAT IS THE NAME OF THE COLD-FLUID) >WHAT

(THIS IS A MANDATORY QUESTION)
>DONTKNOW

(GIVE THE VALUE OF SHELL-DIAMETER IN MM) >DONTKNOW

 SORRY I CAN'T HELP YOU !

NIL
<18>RECORDFILE

RECORD FILE DSK: SES1 CLOSED 04-AUG-86 10:14:41
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        APPPENDIX , SAMPLE SESSION II

*****************************************************************

RECORD FILE DSK: SES2 OPENED 04-AUG-86 10:16:37
(GIVE THE VALUE OF FILM COEFFICIENT OF THE SHELL-SIDE-FLUID IN W / SQ M K) >DONTKNOW
(GIVE THE AREA OF HEAT TRANSFER IN SQ M) >DONTKNOW
(GIVE THE VALUE OF OVERALL HEAT TRANSFER COEFFICIENT IN W / SQ M K) >DONTKNOW
(WHAT IS THE NAME OF THE HOT-FLUID) >MINERAL-OIL
(IS THE MINERAL-OIL SIGNIFICANTLY CORROSIVE) >N
(WHAT IS THE NAME OF THE COLD-FLUID) >WATER
(IS THE WATER SIGNIFICANTLY CORROSIVE) >NO
(DOES THE MINERAL-OIL HAVE SIGNIFICANT FOULING CHARACTERISTICS) >Y
(DOES THE WATER HAVE SIGNIFICANT FOULING CHARACTERISTICS) >N
(PLEASE SPECIFY THE SPECIFIC-HEAT OF THE MINERAL-OIL IN J / KG K) >3100.0
(PLEASE SPECIFY THE SPECIFIC-HEAT OF THE WATER IN J / KG K) >4200.0
(PLEASE SPECIFY THE INLET-TEMP OF THE MINERAL-OIL IN DEG CELSIUS) >108.0
(PLEASE SPECIFY THE OUTLET-TEMP OF THE MINERAL-OIL IN DEG CELSIUS) >76.87
(PLEASE SPECIFY THE INLET-TEMP OF THE WATER IN DEG CELSIUS) >21.65
(PLEASE SPECIFY THE OUTLET-TEMP OF THE WATER IN DEG CELSIUS) >59.43
(WHAT IS THE MASS FLOW RATE OF THE MINERAL-OIL IN KG / SEC) >20.0

                    .
                    .
                    .

<24>RECORDFILE
RECORD FILE DSK: SES2 CLOSED 04-AUG-86 10:18:16
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       APPENDIX        SAMPLE SESSION III

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RECORD FILE DSK: IEL1 OPENED 02-AUG-86 18:44:29
(GIVE THE VALUE OF FILM COEFFICIENT OF THE SHELL-SIDE-FLUID IN W / SQ M K) >WHAT

(" IF THE FLUID IS UNDERGOING CONDENSATION , HERE ARE SOME USEFUL
 VALUES FOR THE  FILM COEFFICIENT. PICK UP A SUITABLE VALUE FROM
 THOSE GIVEN IN THIS TABLE :-
 ------------------------------------------------------------------
       CONDENSING HEAT TRANSFER COEFFICIENTS
 ------------------------------------------------------------------
 NAME OF THE FLUID       CONDITION                       VALUE
                                                     W / sq m K
 ------------------------------------------------------------------
 [1] STEAM ,AMMONIA      10 KPa, NO NON-COND.          10,000
 [2] STEAM ,AMMONIA      10 KPa, 1% NON-COND.          5,000
 [3] STEAM ,AMMONIA      10 KPa, 4% NON-COND.          2,500
 [4] STEAM ,AMMONIA      100 KPa, NO NON-COND.         12,500
 [5] STEAM ,AMMONIA      1000 KPA, NO NON-COND.        20,000
 ------------------------------------------------------------------")
>DONTKNOW

(GIVE THE AREA OF HEAT TRANSFER IN SQ M) >WHAT

("IF THIS THE FIRST ROUND OF CALCULATIONS  OR
 IF YOU KNOW THE VALUE OF OVERALL HEAT TRANSFER COEFFICIENT IN W / SQ M K
 SAY 'DONTKNOW' ELSE
 GIVE THE VALUE FROM THE INITIAL ROUND OF CALCULATION ")
>DONTKNOW

(GIVE THE VALUE OF OVERALL HEAT TRANSFER COEFFICIENT IN W / SQ M K) >WHAT

(" IF THIS IS THE FIRST ROUND OF CALCULATIONS SAY DONTKNOW
 ELSE
 GIVE THE VALUE FROM THE PREVIOUS ROUND ")
>DONTKNOW

(WHAT IS THE NAME OF THE HOT-FLUID) >HOT-GAS

(IS THE HOT-GAS SIGNIFICANTLY CORROSIVE) >Y

(WHAT IS THE NAME OF THE COLD-FLUID) >WATER

(" PLEASE CLASSIFY THE " HOT-GAS " IN ANY ONE OF THE FOLLOWING CATEGORIES :-
```

```
[1] LIGHT LIQUID                                  LIGHT
[2] MEDIUM LIQUID                                 MEDIUM
[3] HEAVY HOT LIQUID                              HEAVY-HOT
[4] HEAVY COLD LIQUID                             HEAVY-COLD
[5] VERY HEAVY HOT LIQUID                         VERY-HEAVY-HOT
[6] VERY HEAVY COLD LIQUID                        VERY-HEAVY-COLD
[7] GAS AT A PRESSURE < 200 KPA                   GAS-200
[8] GAS AT A PRESSURE < 1000 KPA                  GAS-103
[9] GAS AT A PRESSURE < 10000 KPA                 GAS-104
The gas pressure is the absolute pressure
Liquid has to be classified on the basis of viscosity
" " ANSWER BY TYPING THE WORD ON THE RIGHT HAND SIDE ") >GAS-104

(" PLEASE CLASSIFY THE " WATER " IN ANY ONE OF THE FOLLOWING CATEGORIES :-
[1] LIGHT LIQUID                                  LIGHT
[2] MEDIUM LIQUID                                 MEDIUM
[3] HEAVY HOT LIQUID                              HEAVY-HOT
[4] HEAVY COLD LIQUID                             HEAVY-COLD
[5] VERY HEAVY HOT LIQUID                         VERY-HEAVY-HOT
[6] VERY HEAVY COLD LIQUID                        VERY-HEAVY-COLD
[7] GAS AT A PRESSURE < 200 KPA                   GAS-200
[8] GAS AT A PRESSURE < 1000 KPA                  GAS-103
[9] GAS AT A PRESSURE < 10000 KPA                 GAS-104
The gas pressure is the absolute pressure
Liquid has to be classified on the basis of viscosity
" " ANSWER BY TYPING THE WORD ON THE RIGHT HAND SIDE ") >LIGHT

(GIVE THE VALUE OF TUBE OUTSIDE DIAMETER IN MM) >WHAT

(" THE RECOMENDED TUBE DIMENSIONS ARE :-
--------------------------------------------------------------------
TUBE O.D       WALL THICKNESS    TUBE I.D        OUTSIDE SURFACE
mm             mm                mm              sq m / m
--------------------------------------------------------------------
6.0            0.5               5.0             0.019
8.0            1.5               5.0             0.025
10.0           1.5               7.0             0.031
14.0           2.0               10.0            0.044
18.0           2.0               14.0            0.057
20.0           2.0               16.0            0.063
25.0           2.5               20.0            0.079
30.0           2.5               25.0            0.094
38.0           2.5               33.0            0.119
44.5           2.5               39.5            0.139
51.0           2.5               46.0            0.160
--------------------------------------------------------------------
SELECT A SUITABLE TUBE DIAMETER OR TUBE WALL THICKNESS FROM THE ABOVE
TABLE . GENERALLY, TUBES BELOW 20.0 mm O.D ARE NOT RECOMMENDED SINCE
THEY HAVE A LARGE PRESSURE DROP. SMALLER DIAMETER TUBES GIVE LARGER
HEAT TRANSFER AREA FOR THE SAME SHELL DIAMETER.
```

```
YOU MAY SAY DONTKNOW ALSO. ")
>18.0
(GIVE THE VALUE OF TUBE-WALL-THICKNESS IN MM) >2.0
(PLEASE SPECIFY THE INLET-TEMP OF THE HOT-GAS IN DEG CELSIUS) >230.0
(PLEASE SPECIFY THE INLET-TEMP OF THE WATER IN DEG CELSIUS) >109.0
(PLEASE SPECIFY THE OUTLET-TEMP OF THE HOT-GAS IN DEG CELSIUS) >130.0
(PLEASE SPECIFY THE OUTLET-TEMP OF THE WATER IN DEG CELSIUS) >170.0
(PLEASE SPECIFY THE SPECIFIC-HEAT OF THE HOT-GAS IN J / KG K) >3107.0
(PLEASE SPECIFY THE SPECIFIC-HEAT OF THE WATER IN J / KG K) >4280.0
(WHAT IS THE MASS FLOW RATE OF THE HOT-GAS IN KG / SEC) >25.18
(IS THE LIMITATION ON SHELL SIDE PRESSURE-DROP-STRICT) >NO
(IS THE REQUIREMENT OF SHELL SIDE MECHANICAL-CLEANING-FREQUENT) >NO
(GIVE THE VALUE OF ASPECT-RATIO) >20.0
(DOES THE HOT-GAS HAVE SIGNIFICANT FOULING CHARACTERISTICS) >NO
(GIVE THE INLET-PRESSURE OF THE HOT-GAS IN KPA) >36951.0
(GIVE THE NO-OF-BAFFLES) >WHAT
(" THE NO OF BAFFLES DECIDE THE SHELL SIDE REYNOLDS NUMBER
 LOWER VALUE GIVES A LOWER REYNOLDS NUMBER AND LOWER PRESSURE DROP
 IF THE VALUE OF BAFFLE LEAKAGE CORRECTION FACTOR IS LESS THAN
 0.7 REDUCE THE NUMBER OF BAFFLES. THIS INCREASES THE CROSS FLOW AREA
 AT SHELL CENTRE AND HENCE THE CORRECTION FACTOR. ")
>DONTKNOW
(GIVE THE ABSOLUTE VISCOSITY OF THE WATER AT 139.5 DEGREES CELSIUS IN CENTIPOI
S
E) >2.17
(GIVE THE THERMAL CONDUCTIVITY OF THE WATER IN W / M K) >WHAT
(THIS IS A MANDATORY QUESTION)
>0.683
(GIVE THE ABSOLUTE VISCOSITY OF THE THE WATER AT SOME OTHER TEMPERATURE " GIVE
THE TEMPERATURE IN DEGREES CELSIUS FOLLOWED BY
```

```
THE VISCOSITY IN CENTIPOISE ") >109.0 2.7

(GIVE THE VALUE OF FILM COEFFICIENT OF THE TUBE-SIDE-FLUID IN W / SQ M K) >WHAT

(" IF THE FLUID IS UNDERGOING CONDENSATION , HERE ARE SOME USEFUL
 VALUES FOR THE  FILM COEFFICIENT. PICK UP A SUITABLE VALUE FROM
 THOSE GIVEN IN THIS TABLE :-
 -----------------------------------------------------------------
       CONDENSING HEAT TRANSFER COEFFICIENTS
 -----------------------------------------------------------------
 NAME OF THE FLUID       CONDITION                        VALUE
                                                     W / sq m K
 -----------------------------------------------------------------
 [1] STEAM ,AMMONIA      10 KPa, NO NON-COND.          10,000
 [2] STEAM ,AMMONIA      10 KPa, 1% NON-COND.          5,000
 [3] STEAM ,AMMONIA      10 KPa, 4% NON-COND.          2,500
 [4] STEAM ,AMMONIA      100 KPa, NO NON-COND.         12,500
 [5] STEAM ,AMMONIA      1000 KPA, NO NON-COND.        20,000
 -------------------------------------------------------------------")
>DONTKNOW

(GIVE THE THERMAL CONDUCTIVITY OF THE HOT-GAS IN W / M K) >0.1644

(GIVE THE ABSOLUTE VISCOSITY OF THE HOT-GAS AT 180.0 DEGREES CELSIUS IN CENTIP
O
ISE) >0.291

(GIVE THE NO OF TUBE-SIDE-PASSES) >2

(GIVE THE DENSITY OF THE WATER IN KG / CU M) >924.5

(GIVE THE DENSITY OF THE HOT-GAS IN KG / CU M) >99.5

 ---------------------------------------------------------
 THIS IS A TABLE FOR COMPARISION OF THE RESULTS
 ---------------------------------------------------------
 THE HEAT TRANSFER AREA REQUIRED sq m = 345.82829
 THE ACTUAL HEAT TRANSFER AREA AVAILABLE sq m = 597.61589
 SHELL DIAMETER  mm  = 662.91001
 LENGTH OF THE SHELL mm = 13125.618
 SHELL SIDE REYNOLDS NUMBER = 4968.5598
 TUBE SIDE REYNOLDS NUMBER = 21097.693
 SHELL SIDE FLUID = WATER
 TUBE SIDE FLUID = HOT-GAS
 FILM COEFFICIENT OF THE SHELL SIDE  W / sq m K = 2170.1513
 FILM COEFFICIENT OF THE TUBE SIDE  W / sq m K = 1416.2112
 NO OF BAFFLES = 36
 NO OF TUBES = 746
 OVERALL-HEAT TRANSFER COEFFICIENT W / sq m K = 608.95832
 TOTAL SHELL SIDE PRESSURE DROP KPa = 30.586736
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TOTAL TUBE SIDE PRESSURE DROP KPa = 61.123519
L M T D CORRECTION FACTOR = 1.0
THERMAL EFFECTIVENESS = 0.82644627
TUBE SIDE PASSES = 2
SHELL SIDE PASSES = 2

------------------------------------------------------------
THE DIFFERENT CORRECTION-FACTORS FOR HEAT TRANSFER ARE
------------------------------------------------------------
WINDOW CORRECTION FACTOR          = 0.80587929
BAFFLE LEAKAGE CORRECTION FACTOR         = 0.67315776
BUNDLE BYPASS CORRECTION FACTOR          = 0.89673342
ADVERSE TEMPERATURE GRADIENT CORRECTION FACTOR = 1.0
TOTAL CORRECTION FACTOR           = 0.48646344
--------------------------------------------------------------
THE CORRECTION FACTORS FOR PRESSURE DROP ARE
--------------------------------------------------------------
BAFFLE LEAKAGE CORRECTION FACTOR = 0.45001159
BUNDLE BYPASS CORRECTION FACTOR = 0.72424174
END ZONE CORRECTION FACTOR = 2.0

 I THINK YOU ARE SATISFIED WITH THE DESIGN.
 IF YOU ARE , SAY YES.
 IF YOU WANT TO REDESIGN THE HEAT EXCHANGER SAY NO.

>NO

 DO YOU WANT THIS SESSION TO BE STORED ? >YES

 THEN GIVE THE NAME OF THE FILE IN WHICH THIS SESSION IS TO BE STORED >IELSI

Creating IELSI ...
VIL (VERSION 140 "26-JUL-86 02:11:16") (HOLDI EQUAL) OVERALL-HTC OVERALL-HTC
OVERALL-HTC OVERALL-HTC OVERALL-HTC TUBE-DIAMETER TUBE-DIAMETER TUBE-DIAMETER
TUBE-DIAMETER TUBE-DIAMETER RADIUS-OUTSIDE RADIUS-OUTSIDE RADIUS-INSIDE
RADIUS-INSIDE AREA-* AREA-* TUBE-PITCH TUBE-PITCH AREA-ZERO AREA-ZERO AREA-ZER
O
AREA-ZERO AREA-ZERO NO-OF-BAFFLES NO-OF-BAFFLES NO-OF-BAFFLES NO-OF-BAFFLES
NO-OF-BAFFLES CENTRAL-BAFFLE-SPACING-EXACT CENTRAL-BAFFLE-SPACING-EXACT
CENTRAL-BAFFLE-SPACING-APPROX CENTRAL-BAFFLE-SPACING-APPROX
TUBE-SHEET-THICKNESS TUBE-SHEET-THICKNESS TUBE-BUNDLE-DIAMETER
TUBE-BUNDLE-DIAMETER BUNDLE-SHELL-CLEARENCE BUNDLE-SHELL-CLEARENCE ASPECT-RATI
O
ASPECT-RATIO ASPECT-RATIO NO-OF-TUBES NO-OF-TUBES SHELL-LENGTH SHELL-LENGTH
TUBE-LENGTH TUBE-LENGTH SHELL-DIAMETER SHELL-DIAMETER SHELL-DIAMETER
```

```
SHELL-DIAMETER CROSS-FLOW-AREA-AT-SHELL-CENTRE CROSS-FLOW-AREA-AT-SHELL-CENTRE

PERCENT-BAFFLE-CUT PERCENT-BAFFLE-CUT CENTRIANGLE-OF-BAFFLE-CUT
CENTRIANGLE-OF-BAFFLE-CUT REYNOLDS-NO-SHELL REYNOLDS-NO-SHELL BUNDLE-DIAMETER
BUNDLE-DIAMETER WINDOW-AREA-WITHOUT-TUBES WINDOW-AREA-WITHOUT-TUBES
FRACTION-TUBES-IN-ONE-WINDOW FRACTION-TUBES-IN-ONE-WINDOW
UPPER-CENTRIANGLE-OF-BAFFLE-CUT UPPER-CENTRIANGLE-OF-BAFFLE-CUT
FRACTION-TUBES-PURE-CROSS-FLOW FRACTION-TUBES-PURE-CROSS-FLOW
BAFFLE-TIP-CROSS-FLOW-TUBE-NO BAFFLE-TIP-CROSS-FLOW-TUBE-NO
DISTANCE-OF-CROSS-FLOW-PENETRATION DISTANCE-OF-CROSS-FLOW-PENETRATION
TUBE-BAFFLE-HOLE-CLEARENCE TUBE-BAFFLE-HOLE-CLEARENCE
EFFECTIVE-TUBE-ROWS-CROSSED EFFECTIVE-TUBE-ROWS-CROSSED
BUNDLE-SHELL-BYPASS-AREA BUNDLE-SHELL-BYPASS-AREA SHELL-BAFFLE-LEAKAGE-AREA
SHELL-BAFFLE-LEAKAGE-AREA TUBE-BAFFLE-HOLE-LEAKAGE-AREA-PER-BAFFLE
TUBE-BAFFLE-HOLE-LEAKAGE-AREA-PER-BAFFLE WINDOW-CORRECTION-FACTOR
WINDOW-CORRECTION-FACTOR BAFFLE-LEAKAGE-CORRECTION-FACTOR
BAFFLE-LEAKAGE-CORRECTION-FACTOR WINDOW-CORRECTION-FACTOR
WINDOW-CORRECTION-FACTOR RATIO-SB-SM RATIO-SB-SM
BUNDLE-BYPASS-CORRECTION-FACTOR BUNDLE-BYPASS-CORRECTION-FACTOR
WINDOW-AREA-OF-TUBES WINDOW-AREA-OF-TUBES TUBE-NO-PER-WINDOW TUBE-NO-PER-WINDO
W
NET-CROSS-FLOW-AREA-PER-BAFFLE NET-CROSS-FLOW-AREA-PER-BAFFLE
FLOW-DIR-DIST-BET-TWO-TUBES FLOW-DIR-DIST-BET-TWO-TUBES SHELL-BAFFLE-CLEARENCE

SHELL-BAFFLE-CLEARENCE SEALING-STRIP-PAIRS SEALING-STRIP-PAIRS
ADVERSE-TEMP-GRADIENT-VAR ADVERSE-TEMP-GRADIENT-VAR
ADVERSE-TEMP-GRADIENT-CORRECTION-FACTOR ADVERSE-TEMP-GRADIENT-CORRECTION-FACTO
R
VISCOSITY-CORRECTION-FACTOR VISCOSITY-CORRECTION-FACTOR JI-FACTOR-SHELL
JI-FACTOR-SHELL ACTUAL-FILM-COEFF-SHELL ACTUAL-FILM-COEFF-SHELL
ACTUAL-FILM-COEFF-SHELL ACTUAL-FILM-COEFF-SHELL ACTUAL-FILM-COEFF-SHELL
FRICTION-FACTOR-SHELL FRICTION-FACTOR-SHELL IDEAL-TUBE-BANK-PRESSURE-DROP
IDEAL-TUBE-BANK-PRESSURE-DROP PRESSURE-DROP-ALL-BAFFLE-WINDOWS-CROSSED
PRESSURE-DROP-ALL-BAFFLE-WINDOWS-CROSSED PRESSURE-DROP-CROSS-FLOW-BAFFLE-TIPS
PRESSURE-DROP-CROSS-FLOW-BAFFLE-TIPS EQUIVALENT-HYDRAULIC-DIAMETER
EQUIVALENT-HYDRAULIC-DIAMETER PRESSURE-DROP-END-ZONES PRESSURE-DROP-END-ZONES
TOTAL-SHELL-SIDE-PRESSURE-DROP TOTAL-SHELL-SIDE-PRESSURE-DROP TUBE-WALL-TEMP
TUBE-WALL-TEMP TUBE-SIDE-PASSES TUBE-SIDE-PASSES TUBE-SIDE-PASSES
TUBE-SIDE-PASSES TUBE-SIDE-PASSES MASS-VELOCITY-TUBES MASS-VELOCITY-TUBES
CROSS-SECT-AREA-TUBES CROSS-SECT-AREA-TUBES REYNOLDS-NO-TUBES REYNOLDS-NO-TUBE
S
TOTAL-FLOW-AREA-TUBES TOTAL-FLOW-AREA-TUBES FLOW-AREA-TUBES-REQ
FLOW-AREA-TUBES-REQ VELOCITY-TUBES-EXACT VELOCITY-TUBES-EXACT
TUBE-AREA-PER-PASS TUBE-AREA-PER-PASS ACTUAL-FILM-COEFF-TUBES
ACTUAL-FILM-COEFF-TUBES ACTUAL-FILM-COEFF-TUBES ACTUAL-FILM-COEFF-TUBES
ACTUAL-FILM-COEFF-TUBES FRICTION-FACTOR-TUBES FRICTION-FACTOR-TUBES
PRESSURE-DROP-TUBES PRESSURE-DROP-TUBES OVERALL-HTC-ACTUAL OVERALL-HTC-ACTUAL
FLOW-VELOCITY-TUBES FLOW-VELOCITY-TUBES FLOW-VELOCITY-TUBES FLOW-VELOCITY-TUBE
S
FLOW-VELOCITY-TUBES TUBE-WALL-THICKNESS TUBE-WALL-THICKNESS TUBE-WALL-THICKNES
```

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S
TUBE-WALL-THICKNESS VISCOSITY-CORRECTION-FACTOR-TUBES
VISCOSITY-CORRECTION-FACTOR-TUBES AREA-REQ AREA-REQ THERMAL-EFF THERMAL-EFF
HEAT-CAPACITY-RATIO HEAT-CAPACITY-RATIO DELTA DELTA LMTD-CORRECTION
LMTD-CORRECTION END-ZONE-CORRECTION-FACTOR END-ZONE-CORRECTION-FACTOR

 GIVE THE NAME OF THE FILE IN WHICH
 THE SESSION IS TO BE STORED :->IEL2

RECORD FILE DSK: IEL1 CLOSED 02-AUG-86 19:00:56

RECORD FILE DSK: IEL2 OPENED 02-AUG-86 19:01:02
(GIVE THE VALUE OF FILM COEFFICIENT OF THE SHELL-SIDE-FLUID IN W / SQ M K) >DONTKNOW

(GIVE THE AREA OF HEAT TRANSFER IN SQ M) >DONTKNOW

(GIVE THE VALUE OF OVERALL HEAT TRANSFER COEFFICIENT IN W / SQ M K) >1000.0

(GIVE THE VALUE OF TUBE OUTSIDE DIAMETER IN MM) >18.0

(GIVE THE VALUE OF ASPECT-RATIO) >20.0

(GIVE THE NO-OF-BAFFLES) >40

(GIVE THE VALUE OF FILM COEFFICIENT OF THE TUBE-SIDE-FLUID IN W / SQ M K) >DONTKNOW

(GIVE THE NO OF TUBE-SIDE-PASSES) >2

(GIVE THE VALUE OF TUBE-WALL-THICKNESS IN MM) >2.0

 ------------------------------------------------------------------
 THIS IS A TABLE FOR COMPARISION OF THE RESULTS
 ------------------------------------------------------------------
 THE HEAT TRANSFER AREA REQUIRED sq m = 219.89553
 THE ACTUAL HEAT TRANSFER AREA AVAILABLE sq m = 210.59501
 SHELL DIAMETER  mm  = 468.39711
 LENGTH OF THE SHELL mm = 9274.2629
 SHELL SIDE REYNOLDS NUMBER = 10704.942
 TUBE SIDE REYNOLDS NUMBER = 43002.101
 SHELL SIDE FLUID = WATER
 TUBE SIDE FLUID = HOT-GAS
 FILM COEFFICIENT OF THE SHELL SIDE  W / sq m K = 3333.5158
 FILM COEFFICIENT OF THE TUBE SIDE  W / sq m K = 2731.5916
 NO OF BAFFLES = 40
 NO OF TUBES = 366
 OVERALL-HEAT TRANSFER COEFFICIENT W / sq m K = 957.70486
 TOTAL SHELL SIDE PRESSURE DROP KPa = 90.614976
 TOTAL TUBE SIDE PRESSURE DROP KPa = 163.29022
 L M T D CORRECTION FACTOR = 1.0
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THERMAL EFFECTIVENESS = 0.82644627
TUBE SIDE PASSES = 2
SHELL SIDE PASSES = 2

----------------------------------------------------------
THE DIFFERENT CORRECTION-FACTORS FOR HEAT TRANSFER ARE
----------------------------------------------------------
WINDOW CORRECTION FACTOR          = 0.83723931
BAFFLE LEAKAGE CORRECTION FACTOR          = 0.63191961
BUNDLE BYPASS CORRECTION FACTOR           = 0.88072925
ADVERSE TEMPERATURE GRADIENT CORRECTION FACTOR = 1.0
TOTAL CORRECTION FACTOR           = 0.46596561
------------------------------------------------------------
THE CORRECTION FACTORS FOR PRESSURE DROP ARE
------------------------------------------------------------
BAFFLE LEAKAGE CORRECTION FACTOR = 0.40614426
BUNDLE BYPASS CORRECTION FACTOR = 0.68664708
END ZONE CORRECTION FACTOR = 2.0


I THINK YOU ARE SATISFIED WITH THE DESIGN.
IF YOU ARE , SAY YES.
IF YOU WANT TO REDESIGN THE HEAT EXCHANGER SAY NO.


>N


DO YOU WANT THIS SESSION TO BE STORED ? >N

NIL (VERSION 140 "26-JUL-86 02:11:16") (HOLDI EQUAL) OVERALL-HTC OVERALL-HTC
OVERALL-HTC OVERALL-HTC OVERALL-HTC TUBE-DIAMETER TUBE-DIAMETER TUBE-DIAMETER
TUBE-DIAMETER TUBE-DIAMETER RADIUS-OUTSIDE RADIUS-OUTSIDE RADIUS-INSIDE
RADIUS-INSIDE AREA-* AREA-* TUBE-PITCH TUBE-PITCH AREA-ZERO AREA-ZERO AREA-ZER
O
AREA-ZERO AREA-ZERO NO-OF-BAFFLES NO-OF-BAFFLES NO-OF-BAFFLES NO-OF-BAFFLES
NO-OF-BAFFLES CENTRAL-BAFFLE-SPACING-EXACT CENTRAL-BAFFLE-SPACING-EXACT
CENTRAL-BAFFLE-SPACING-APPROX CENTRAL-BAFFLE-SPACING-APPROX
TUBE-SHEET-THICKNESS TUBE-SHEET-THICKNESS TUBE-BUNDLE-DIAMETER
TUBE-BUNDLE-DIAMETER BUNDLE-SHELL-CLEARENCE BUNDLE-SHELL-CLEARENCE ASPECT-RATI
O
ASPECT-RATIO ASPECT-RATIO NO-OF-TUBES NO-OF-TUBES SHELL-LENGTH SHELL-LENGTH
TUBE-LENGTH TUBE-LENGTH SHELL-DIAMETER SHELL-DIAMETER SHELL-DIAMETER
SHELL-DIAMETER CROSS-FLOW-AREA-AT-SHELL-CENTRE CROSS-FLOW-AREA-AT-SHELL-CENTRE

PERCENT-BAFFLE-CUT PERCENT-BAFFLE-CUT CENTRIANGLE-OF-BAFFLE-CUT
CENTRIANGLE-OF-BAFFLE-CUT REYNOLDS-NO-SHELL REYNOLDS-NO-SHELL BUNDLE-DIAMETER
BUNDLE-DIAMETER WINDOW-AREA-WITHOUT-TUBES WINDOW-AREA-WITHOUT-TUBES
FRACTION-TUBES-IN-ONE-WINDOW FRACTION-TUBES-IN-ONE-WINDOW
UPPER-CENTRIANGLE-OF-BAFFLE-CUT UPPER-CENTRIANGLE-OF-BAFFLE-CUT
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FRACTION-TUBES-PURE-CROSS-FLOW FRACTION-TUBES-PURE-CROSS-FLOW
BAFFLE-TIP-CROSS-FLOW-TUBE-NO BAFFLE-TIP-CROSS-FLOW-TUBE-NO
DISTANCE-OF-CROSS-FLOW-PENETRATION DISTANCE-OF-CROSS-FLOW-PENETRATION
TUBE-BAFFLE-HOLE-CLEARENCE TUBE-BAFFLE-HOLE-CLEARENCE
EFFECTIVE-TUBE-ROWS-CROSSED EFFECTIVE-TUBE-ROWS-CROSSED
BUNDLE-SHELL-BYPASS-AREA BUNDLE-SHELL-BYPASS-AREA SHELL-BAFFLE-LEAKAGE-AREA
SHELL-BAFFLE-LEAKAGE-AREA TUBE-BAFFLE-HOLE-LEAKAGE-AREA-PER-BAFFLE
TUBE-BAFFLE-HOLE-LEAKAGE-AREA-PER-BAFFLE WINDOW-CORRECTION-FACTOR
WINDOW-CORRECTION-FACTOR BAFFLE-LEAKAGE-CORRECTION-FACTOR
BAFFLE-LEAKAGE-CORRECTION-FACTOR WINDOW-CORRECTION-FACTOR
WINDOW-CORRECTION-FACTOR RATIO-SB-SM RATIO-SB-SM
BUNDLE-BYPASS-CORRECTION-FACTOR BUNDLE-BYPASS-CORRECTION-FACTOR
WINDOW-AREA-OF-TUBES WINDOW-AREA-OF-TUBES TUBE-NO-PER-WINDOW TUBE-NO-PER-WINDO
W
NET-CROSS-FLOW-AREA-PER-BAFFLE NET-CROSS-FLOW-AREA-PER-BAFFLE
FLOW-DIR-DIST-BET-TWO-TUBES FLOW-DIR-DIST-BET-TWO-TUBES SHELL-BAFFLE-CLEARENCE

SHELL-BAFFLE-CLEARENCE SEALING-STRIP-PAIRS SEALING-STRIP-PAIRS
ADVERSE-TEMP-GRADIENT-VAR ADVERSE-TEMP-GRADIENT-VAR
ADVERSE-TEMP-GRADIENT-CORRECTION-FACTOR ADVERSE-TEMP-GRADIENT-CORRECTION-FACTO
R
VISCOSITY-CORRECTION-FACTOR VISCOSITY-CORRECTION-FACTOR JI-FACTOR-SHELL
JI-FACTOR-SHELL ACTUAL-FILM-COEFF-SHELL ACTUAL-FILM-COEFF-SHELL
ACTUAL-FILM-COEFF-SHELL ACTUAL-FILM-COEFF-SHELL ACTUAL-FILM-COEFF-SHELL
FRICTION-FACTOR-SHELL FRICTION-FACTOR-SHELL IDEAL-TUBE-BANK-PRESSURE-DROP
IDEAL-TUBE-BANK-PRESSURE-DROP PRESSURE-DROP-ALL-BAFFLE-WINDOWS-CROSSED
PRESSURE-DROP-ALL-BAFFLE-WINDOWS-CROSSED PRESSURE-DROP-CROSS-FLOW-BAFFLE-TIPS
PRESSURE-DROP-CROSS-FLOW-BAFFLE-TIPS EQUIVALENT-HYDRAULIC-DIAMETER
EQUIVALENT-HYDRAULIC-DIAMETER PRESSURE-DROP-END-ZONES PRESSURE-DROP-END-ZONES
TOTAL-SHELL-SIDE-PRESSURE-DROP TOTAL-SHELL-SIDE-PRESSURE-DROP TUBE-WALL-TEMP
TUBE-WALL-TEMP TUBE-SIDE-PASSES TUBE-SIDE-PASSES TUBE-SIDE-PASSES
TUBE-SIDE-PASSES TUBE-SIDE-PASSES MASS-VELOCITY-TUBES MASS-VELOCITY-TUBES
CROSS-SECT-AREA-TUBES CROSS-SECT-AREA-TUBES REYNOLDS-NO-TUBES REYNOLDS-NO-TUBE
S
TOTAL-FLOW-AREA-TUBES TOTAL-FLOW-AREA-TUBES FLOW-AREA-TUBES-REQ
FLOW-AREA-TUBES-REQ VELOCITY-TUBES-EXACT VELOCITY-TUBES-EXACT
TUBE-AREA-PER-PASS TUBE-AREA-PER-PASS ACTUAL-FILM-COEFF-TUBES
ACTUAL-FILM-COEFF-TUBES ACTUAL-FILM-COEFF-TUBES ACTUAL-FILM-COEFF-TUBES
ACTUAL-FILM-COEFF-TUBES FRICTION-FACTOR-TUBES FRICTION-FACTOR-TUBES
PRESSURE-DROP-TUBES PRESSURE-DROP-TUBES OVERALL-HTC-ACTUAL OVERALL-HTC-ACTUAL
FLOW-VELOCITY-TUBES FLOW-VELOCITY-TUBES FLOW-VELOCITY-TUBES FLOW-VELOCITY-TUBE
S
FLOW-VELOCITY-TUBES TUBE-WALL-THICKNESS TUBE-WALL-THICKNESS TUBE-WALL-THICKNES
S
TUBE-WALL-THICKNESS VISCOSITY-CORRECTION-FACTOR-TUBES
VISCOSITY-CORRECTION-FACTOR-TUBES AREA-REQ AREA-REQ THERMAL-EFF THERMAL-EFF
HEAT-CAPACITY-RATIO HEAT-CAPACITY-RATIO DELTA DELTA LMTD-CORRECTION
LMTD-CORRECTION END-ZONE-CORRECTION-FACTOR END-ZONE-CORRECTION-FACTOR
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GIVE THE NAME OF THE FILE IN WHICH
THE SESSION IS TO BE STORED :->IEL3

RECORD FILE DSK: IEL2 CLOSED 02-AUG-86 19:11:39

RECORD FILE DSK: IEL3 OPENED 02-AUG-86 19:11:40
(GIVE THE VALUE OF FILM COEFFICIENT OF THE SHELL-SIDE-FLUID IN W / SQ M K) >DONTKNOW

(GIVE THE AREA OF HEAT TRANSFER IN SQ M) >DONTKNOW

(GIVE THE VALUE OF OVERALL HEAT TRANSFER COEFFICIENT IN W / SQ M K) >1000.0

(GIVE THE VALUE OF TUBE OUTSIDE DIAMETER IN MM) >18.0

(GIVE THE VALUE OF ASPECT-RATIO) >22.0

(GIVE THE NO-OF-BAFFLES) >50

(GIVE THE VALUE OF FILM COEFFICIENT OF THE TUBE-SIDE-FLUID IN W / SQ M K) >WHAT

(" IF THE FLUID IS UNDERGOING CONDENSATION , HERE ARE SOME USEFUL
 VALUES FOR THE  FILM COEFFICIENT. PICK UP A SUITABLE VALUE FROM
 THOSE GIVEN IN THIS TABLE :-
 ----------------------------------------------------------------------
       CONDENSING HEAT TRANSFER COEFFICIENTS
 ----------------------------------------------------------------------
 NAME OF THE FLUID      CONDITION                         VALUE
                                                       W / sq m K
 ----------------------------------------------------------------------
 [1] STEAM ,AMMONIA     10 KPa, NO NON-COND.            10,000
 [2] STEAM ,AMMONIA     10 KPa, 1% NON-COND.            5,000
 [3] STEAM ,AMMONIA     10 KPa, 4% NON-COND.            2,500
 [4] STEAM ,AMMONIA     100 KPa, NO NON-COND.           12,500
 [5] STEAM ,AMMONIA     1000 KPA, NO NON-COND.          20,000
 ----------------------------------------------------------------------")
>DONTKNOW

(GIVE THE NO OF TUBE-SIDE-PASSES) >2

(GIVE THE VALUE OF TUBE-WALL-THICKNESS IN MM) >WHAT

(" THE RECOMENDED TUBE DIMENSIONS ARE :-
 ----------------------------------------------------------------------
 TUBE O.D        WALL THICKNESS   TUBE I.D         OUTSIDE SURFACE
 mm              mm               mm               sq m / m
 ----------------------------------------------------------------------
 6.0             0.5              5.0              0.019
 8.0             1.5              5.0              0.025
 10.0            1.5              7.0              0.031
 14.0            2.0              10.0             0.044
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18.0           2.0            14.0           0.057
20.0           2.0            16.0           0.063
25.0           2.5            20.0           0.079
30.0           2.5            25.0           0.094
38.0           2.5            33.0           0.119
44.5           2.5            39.5           0.139
51.0           2.5            46.0           0.160
------------------------------------------------------------------
SELECT A SUITABLE TUBE DIAMETER OR TUBE WALL THICKNESS FROM THE ABOVE
TABLE . GENERALLY, TUBES BELOW 20.0 mm O.D ARE NOT RECOMMENDED SINCE
THEY HAVE A LARGE PRESSURE DROP. SMALLER DIAMETER TUBES GIVE LARGER
HEAT TRANSFER AREA FOR THE SAME SHELL DIAMETER.
YOU MAY SAY DONTKNOW ALSO. ")
>2.0

------------------------------------------------------------
THIS IS A TABLE FOR COMPARISION OF THE RESULTS
------------------------------------------------------------
THE HEAT TRANSFER AREA REQUIRED sq m = 209.11471
THE ACTUAL HEAT TRANSFER AREA AVAILABLE sq m = 210.59501
SHELL DIAMETER  mm  = 453.76443
LENGTH OF THE SHELL mm = 9892.0646
SHELL SIDE REYNOLDS NUMBER = 12789.038
TUBE SIDE REYNOLDS NUMBER = 45885.944
SHELL SIDE FLUID = WATER
TUBE SIDE FLUID = HOT-GAS
FILM COEFFICIENT OF THE SHELL SIDE  W / sq m K = 3655.1002
FILM COEFFICIENT OF THE TUBE SIDE  W / sq m K = 2883.5154
NO OF BAFFLES = 50
NO OF TUBES = 343
OVERALL-HEAT TRANSFER COEFFICIENT W / sq m K = 1007.0789
TOTAL SHELL SIDE PRESSURE DROP KPa = 98.640654
TOTAL TUBE SIDE PRESSURE DROP KPa = 173.30860
L M T D CORRECTION FACTOR = 1.0
THERMAL EFFECTIVENESS = 0.82644627
TUBE SIDE PASSES = 2
SHELL SIDE PASSES = 2

----------------------------------------------------------
THE DIFFERENT CORRECTION-FACTORS FOR HEAT TRANSFER ARE
----------------------------------------------------------
WINDOW CORRECTION FACTOR          = 0.87062163
BAFFLE LEAKAGE CORRECTION FACTOR          = 0.59605844
BUNDLE BYPASS CORRECTION FACTOR          = 0.87903944
ADVERSE TEMPERATURE GRADIENT CORRECTION FACTOR = 1.0
TOTAL CORRECTION FACTOR          = 0.45616994
------------------------------------------------------------
THE CORRECTION FACTORS FOR PRESSURE DROP ARE
------------------------------------------------------------
BAFFLE LEAKAGE CORRECTION FACTOR = 0.37371063
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BUNDLE BYPASS CORRECTION FACTOR = 0.68275479
END ZONE CORRECTION FACTOR = 2.0

I THINK YOU ARE SATISFIED WITH THE DESIGN.
IF YOU ARE , SAY YES.
IF YOU WANT TO REDESIGN THE HEAT EXCHANGER SAY NO.

>YES

GIVE THE NAME OF THE FILE IN WHICH THE OUTPUT IS TO BE STORED :->IEL4

RECORD FILE DSK: IEL3 CLOSED 02-AUG-86 19:17:48

RECORD FILE DSK: IEL4 OPENED 02-AUG-86 19:20:59
----------------------------------------------------------------
THIS IS A TABLE FOR COMPARISION OF THE RESULTS
----------------------------------------------------------------
THE HEAT TRANSFER AREA REQUIRED sq m = 209.11471
THE ACTUAL HEAT TRANSFER AREA AVAILABLE sq m = 210.59501
SHELL DIAMETER  mm  = 453.76443
LENGTH OF THE SHELL mm = 9892.0646
SHELL SIDE REYNOLDS NUMBER = 12789.038
TUBE SIDE REYNOLDS NUMBER = 45885.944
SHELL SIDE FLUID = WATER
TUBE SIDE FLUID = HOT-GAS
FILM COEFFICIENT OF THE SHELL SIDE  W / sq m K = 3655.1002
FILM COEFFICIENT OF THE TUBE SIDE  W / sq m K = 2883.5154
NO OF BAFFLES = 50
NO OF TUBES = 343
OVERALL-HEAT TRANSFER COEFFICIENT W / sq m K = 1007.0789
TOTAL SHELL SIDE PRESSURE DROP KPa = 98.640654
TOTAL TUBE SIDE PRESSURE DROP KPa = 173.30860
L M T D CORRECTION FACTOR = 1.0
THERMAL EFFECTIVENESS = 0.82644627
TUBE SIDE PASSES = 2
SHELL SIDE PASSES = 2

--------------------------------------------------------------
THE DIFFERENT CORRECTION-FACTORS FOR HEAT TRANSFER ARE
--------------------------------------------------------------
WINDOW CORRECTION FACTOR       = 0.87062163
BAFFLE LEAKAGE CORRECTION FACTOR         = 0.59605844
BUNDLE BYPASS CORRECTION FACTOR          = 0.87903944
ADVERSE TEMPERATURE GRADIENT CORRECTION FACTOR = 1.0
TOTAL CORRECTION FACTOR        = 0.45616994
----------------------------------------------------------------
THE CORRECTION FACTORS FOR PRESSURE DROP ARE
```

```
--------------------------------------------------------------
BAFFLE LEAKAGE CORRECTION FACTOR = 0.37371063
BUNDLE BYPASS CORRECTION FACTOR = 0.68275479
END ZONE CORRECTION FACTOR = 2.0
------------------------------------------------------------------
THE SHELL SIDE PARAMETERS ARE
------------------------------------------------------------------
FLUID NAME = WATER
SHELL DIAMETER mm = 453.76443
LENGTH OF THE SHELL mm = 9982.8176
FILM COEFFICIENT W / sq m K = 3655.1002
REYNOLDS NUMBER = 12789.038
PRANDTL NUMBER = 13.598242
NO OF BAFFLES = 50
CENTRAL BAFFLE SPACING mm = 380.46402
PERCENTAGE OF BAFFLE CUT = 31.971153
CENTRIANGLE OF BAFFLE CUT deg = 137.73888
UPPER CENTRIANGLE OF BAFFLE CUT  deg = 138.09998
BUNDLE TO SHELL INSIDE DIAMETER CLEARENCE mm = 14.268822
NET WINDOW FLOW AREA  sq mm = 5012.3685
NO OF TUBES IN ONE BAFFLE WINDOW  = 0.27727664
ASPECT RATIO = 22.0
CROSS FLOW AREA AT THE SHELL CENTRELINE sq mm = 19435.614
FRACTION NO OF TUBES IN ONE WINDOW = 0.27727664
WINDOW AREA WITHOUT TUBES sq mm = 22125.515
FRACTION NO OF TUBES IN PURE CROSS FLOW = 0.44544671
NO OF TUBES IN CROSS FLOW BETWEEN BAFFLE TIPS = 8.3970737
NO OF TUBE ROWS CROSSED IN BAFFLE WINDOW = 5.6634052
BUNDLE TO SHELL BYPASS AREA sq mm = 2004.5971
SHELL TO BAFFLE LEAKAGE AREA sq mm = 2196.6406
TUBE TO BAFFLE HOLE LEAKAGE AREA sq mm = 5731.1212
SHELL TO BAFFLE CLEARENCE mm = 4.9150576
NO OF SEALING STRIP PAIRS = 0
VISCOSITY CORRECTION FACTOR = 1.0105068
NO OF SHELL SIDE PASSES = 2
TOTAL SHELL SIDE PRESSURE DROP  K Pa = 98.640654
------------------------------------------------------------------
THE TUBE SIDE PARAMETERS ARE
------------------------------------------------------------------

NAME OF THE FLUID = HOT-GAS
TUBE DIAMETER  mm  = 18.0
TUBE WALL THICKNESS mm = 2.0
FILM HEAT TRANSFER COEFFICIENT W /sq m K = 2883.5154
REYNOLDS NUMBER = 45885.944
PRANDTL NUMBER = 5.4996168
NO OF TUBES = 343
NO OF TUBE SIDE PASSES = 2
TUBE BUNDLE TYPE = U-TUBE-SHEET
TOTAL TUBE SIDE PRESSURE DROP  K Pa = 173.30860
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RECORD FILE DSK: IEL4 CLOSED 02-AUG-86 19:22:03